Preface

This textbook is designed for the students at Upper Secondary Level (i.e. Grade 10) with the foundation standards falling into the three broad strands mentioned below:

1. Mechanics
2. Energy
3. Modern Physics

The first two strands cover the elementary level of physics whilst the final chapter deals with Modern Physics, which is to be further dealt with in Grade 11. Despite a greater emphasis placed on introductory physics, it is gratifying to note that this updated edition is also in a position to serve as a launch platform for the beginners who have the future potential to become outstanding scholars of physics.

Each chapter includes relevant graphical representations and photographs, not to mention the learner-friendly applications. What's more, the contents cover not only the learning objectives and outcomes but also relate to the conceptual questions, concept maps and links to laboratory work, enabling the learners to acquire considerable knowledge of traditional physics application problems and creative thinking skills. Better still, it may also help the students switch from the typical rote learning to the soft skills practiced commonly in the modern classrooms today. Accordingly, this textbook meets the requirements for a fundamental physics course both in terms of scope and sequence.

In addition, this textbook is intended to foster the **5C's**, the key to success in developing **21st century skills for learning** in the classrooms:

- **Collaboration**
    - in lessons students will be working in groups, to share ideas with their classmates and to find the solution together
- **Communication**
    - students will develop verbal and non-verbal communication skills in group works
- **Critical Thinking and Problem Solving**
    - students will be given interesting problems to solve
    - finding and explaining solutions, looking for correcting errors
- **Creativity and Innovation**
    - thinking 'outside the box' is an important 21st century skill.
    - students will be encouraged to explore new ideas and solve problems in new ways.
- **Citizenship**
    - students will join the school community and develop fairness and conflict resolution skills.

Furthermore, it is organized in such a way that the topics are introduced conceptually with the degree of intensity increased gradually. Besides, the developmental progression is established with the help of the precise definitions and principles in addition to the problems and their practical applications. Remarkably, the textbook also makes sure that the students' problem-solving skills in one topic are consolidated with the key concepts before moving on to another topic. Thoroughly reviewed and revised, this edition bears comparison with most of the contemporary textbooks aimed at the same target audience.

It goes without saying that physics is the study of the world around us. With this textbook as the standard source of information on physics, the students are expected to have greater awareness of what is happening around them every day in the context of physics. Simultaneously, they are also expected to develop superior skills when it comes to their concept formation, comprehension, analysis, synthesis, and evolution, thereby making themselves able to participate in all the lessons actively through the **5C's**, which constitute the integral part of **21st century skills for learning.**

CONTENTS

MECHANICS

MODERN PHYSICS

CHAPTER 1

UNITS AND MEASUREMENTS

Physics, like any other branch of science, is based on systematic observations and precise measurements. Experiments are an essential feature of science. Most experiments in Physics require the observations made to be quantitative rather than qualitative.

Learning Outcomes

It is expected that students will

- work accurately with basic and derived units of measurement.
- work accurately with standard measurements and conversions between different system of units.
- correctly use the symbols for physical quantities.
- develop skills in accurate measurement of length, mass and time.
- solve problems demonstrating proper use of units, quantities and scientific notation.

1.1 BASIC AND DERIVED UNITS

Measurement essentially is a comparison process. Quantitative measurements must be expressed in numerical comparison to certain agreed upon set of standards. A standard quantity of some kind, referred to as a unit, is first established. Standard is something or a reference used as a measure for length, mass and time. Unit is a quantity or an amount used as a standard of measurement.

There are many things in the world that can be measured accurately. These things are known as 'physical quantities'. A physical quantity is the quantity that can be measured, and consists of a numerical magnitude and a unit. It can be expressed as

$$Q = \mathrm{N\,u}$$

where Q is the physical quantity, N is a dimensionless number and u is the unit. For example, the length of an object is $l = 10\ m$, where 'l' is physical quantity, '10' is the numerical number and 'm' is the unit .

Physical quantities can be classified as the basic type (length, mass, time, temperature, electric current, amount of substance, luminous intensity) and the derived type (area, volume, velocity, work, energy, etc.). Their units are also called the basic units and the derived units. A derived unit is a unit of measurement formed by combining the basic (or base) units of a system.

For example, speed $= \dfrac{\text{distance}}{\text{time}}$, the base unit of distance is 'm' and that of time is 's'.
Therefore the unit of speed is 'm s^{-1}'. This is a derived unit.

Reviewed Exercise

- Explain each of the following terms in your own words:
  physical quantity, basic unit, derived unit.

Key Words : physical quantity, standard, unit, basic unit, derived unit

1.2 SYSTEM OF UNITS

In this text book, we shall be using the following system of units.

(i) the British system
(ii) the metric system
(iii) the SI units

The British system is based on foot (ft), pound (lb) and second (s) and is therefore also called the FPS system.
The metric system consists of (i) the CGS system and (ii) the MKS system.
The CGS system is based on centimetre (cm), gram (g) and second (s).
The MKS system is based on metre (m), kilogram (kg) and second (s).
These two systems are alike in the sense that units of length and mass of one system may be converted to those of the other by using powers of 10. (e.g. 1 m = 10^2 cm, 1 kg = 10^3 g)
The SI unit is just the modified form of the MKS system of units.

Scientists all over the world like to work with a consistent and coherent system of units. In 1960, the Eleventh General Conference of Weights and Measures in France recommended an International System of Units based on the metric system of units. This recommendation was accepted as SI units (full name, 'Systeme International d' Units').

The SI unit has seven base units and all other units are derived from these base units by multiplying or dividing one unit by another without introducing numerical factors. Table 1.1 shows the seven base units of SI system.

Table 1.1 Seven base units of SI system

Physical quantity	Symbol	SI unit
Length	ℓ, d, s, etc.	metre (m)
Mass	m	kilogram (kg)
Time	t	second (s)
Electric current	I	ampere (A)
Temperature	T	kelvin (K)
Amount of substance	n	mole (mol)
Luminous intensity	L	candela (cd)

Reviewed Exercise

1. Write down the value of (a) 1 564 mm in m, and (b) 1 750 g in kg.
2. In each of the following pairs, which quantity is larger?
   (a) 2 km (or) 2 500 m, (b) 2 m (or) 1 500 mm, (c) 2 000 g (or) 3 kg

Key Words : SI units, metric system, British system

1.3 PREFIXES

Sometimes a physical quantity is too big (or) too small to be conveniently expressed in basic SI units. Prefixes are needed to be used. Prefixes are multiples or sub-multiples of 10. Table 1.2 shows some prefixes used in SI units.

Table 1.2 Some prefixes for SI units

Prefix	Symbol	Factor
femto	f	10^{-15}
pico	p	10^{-12}
nano	n	10^{-9}
micro	μ	10^{-6}
milli	m	10^{-3}
centi	c	10^{-2}
deci	d	10^{-1}

Prefix	Symbol	Factor
deca	da	10^{1}
hecto	h	10^{2}
kilo	k	10^{3}
mega	M	10^{6}
giga	G	10^{9}
tera	T	10^{12}

Scientific notation (or) standard form may be written as follows:

Place the decimal point after the first nonzero digit. Then determine the power of 10 by counting the number of places we have moved the original decimal point to the marked decimal point. If we moved the point to the left, then power is positive and if we moved it to the right, it is negative.

Reviewed Exercise

- Write the following numbers in scientific notation.
  (a) 320 000 (b) 0.000 075

Key Words : scientific notation

1.4 STANDARDS AND UNITS

(a) The Unit of Length

The standard of length is metre. The metre was originally defined as the length between two marks on a platinum-iridium rod at $0\,^{\circ}\mathrm{C}$, kept at the International Bureau of Weights and Measures at Sevres, near Paris. Copies of the standard were sent all over the world.

Nowadays the standard of length used is based on the wavelength of orange-red light emitted by a krypton 86 isotope. A metre is now defined as the length equivalent to 1 650 763.73 times the wavelength of this orange-red light.

By the 1970s, the speed of light has become one of the most precisely determined quantities. As a result, in 1983 the metre was given a new operational definition. The metre is the length of the path travelled by light in vacuum during a time interval of $\frac{1}{299\,792\,458}$ of a second.

In the CGS system the unit of length is the centimetre (cm) and

$$1\,\mathrm{cm} = \frac{1}{100}\,\mathrm{m} = 10^{-2}\,\mathrm{m}$$

In the FPS system the unit of length is the foot (ft) and

$$1\,\mathrm{ft} = 0.3048\,\mathrm{m}$$

The unit of length used by particle physicists is the 'Fermi' or 'femtometre' (fm) given by

$$1\,\mathrm{fm} = 10^{-15}\,\mathrm{m}$$

In the field of optics, physicists use the unit angstrom (Å), where

$$1\,\text{Å} = 10^{-10}\,\mathrm{m}$$

In astronomy, the most suitable units are the astronomical unit (AU) and the light year unit (*l*y). The light year is the distance which light travels in one year.

$$1\,\mathrm{AU} = 1.496 \times 10^{11}\,\mathrm{m}$$

$$1\,ly = 9.461 \times 10^{15}\,\mathrm{m}$$

The largest unit of length is the 'parsec'(pc).

$$1\,\mathrm{pc} = 3.084 \times 10^{16}\,\mathrm{m}$$

(b) The Unit of Mass

The standard of mass is a cylinder of 1 kg mass made of platinum-iridium alloy. It serves as a standard of mass for international use. Figure 1.1 shows the standard metre and standard kilogram which are kept at the International Bureau of Weights and Measures at Sevres, near Paris. Prototypes of standard kilogram are distributed to research academies and laboratories situated in all parts of the world.

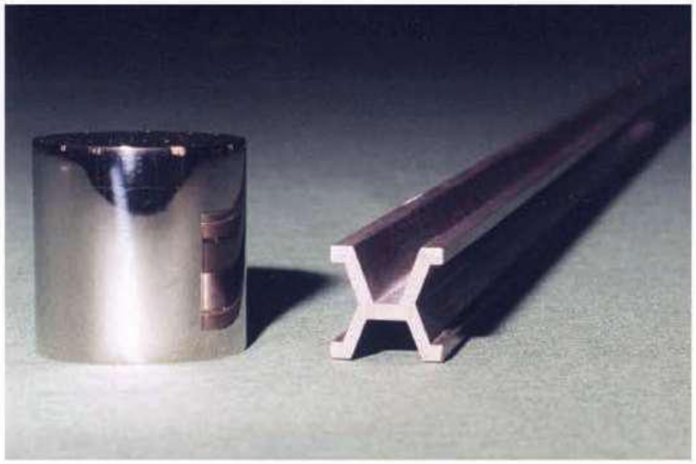

Figure 1.1 The standard kilogram and the standard metre kept at International Bureau of Weights and Measures

[https://www.bipm.org/en/measurement-units/history-si/metre-kilo.html]

(c) The Unit of Time

The SI base unit of time is the second. The second was originally defined as $\frac{1}{60\times60\times24}$ of a day, one day being the time it takes the Earth to rotate once. But the Earth's rotation is not quite constant. So, for accuracy, the second is now defined in terms of something that never changes: the frequency of oscillation which can occur from a cesium atom. A particular frequency 9 192 631 770 s^{-1} emitted or absorbed by a cesium atom is used to define 1 s.

Reviewed Exercise

- If the density of ice is 920 kg m^{-3} , convert this value to g cm^{-3} .

Key Words: light-year, oscillation, frequency

Symbols for Physical Quantities

It is said that 'mathematics is the language of physics'. Physical laws and principles can be fully and effectively represented in mathematical forms. Since we have to express the relation between physical quantities in mathematical equations it is necessary that the symbols for the physical quantities be short and precise.

Some commonly used symbols for physical quantities are:
' s ' for displacement, ' v ' for velocity, ' a ' for acceleration and ' F ' for force .

1.5 MEASUREMENT OF LENGTH

To measure the length of objects some standard objects have to be used. For everyday use, the standard may be a yard stick, ruler, metre stick and so on. Lengths are usually measured in metre, centimetre or millimetre. Greater lengths are measured in kilometre.

In length measurement, we must choose an instrument that is suitable for the length to be measured. Figure 1.2, 1.3 and 1.4 show some various instruments for measurement of length. Table 1.3 summarizes the commonly used instruments, their ranges and accuracies.

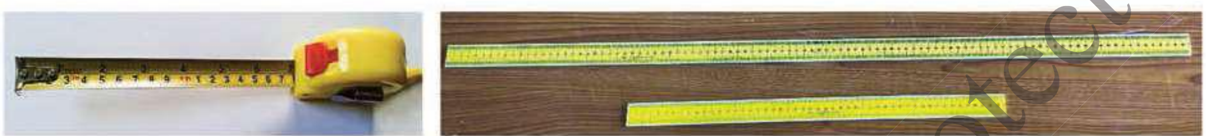

Figure 1.2 Measuring tape, metre rule and half-meter rule

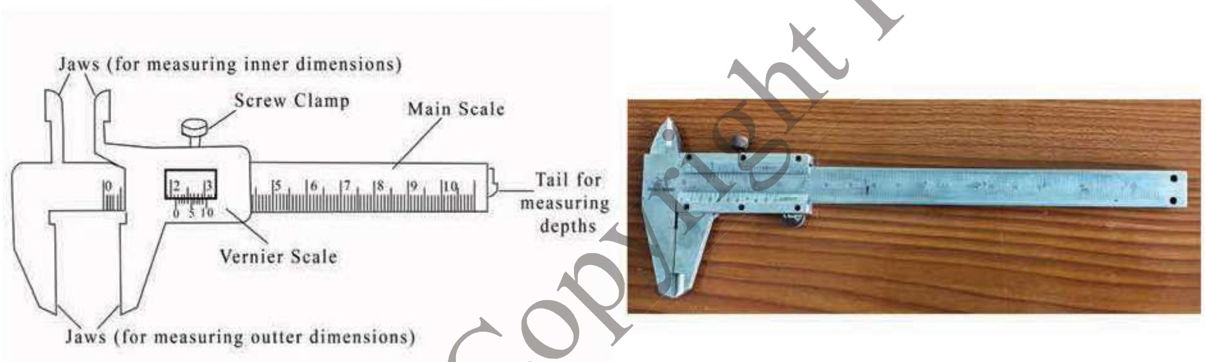

Figure 1.3 Vernier calipers

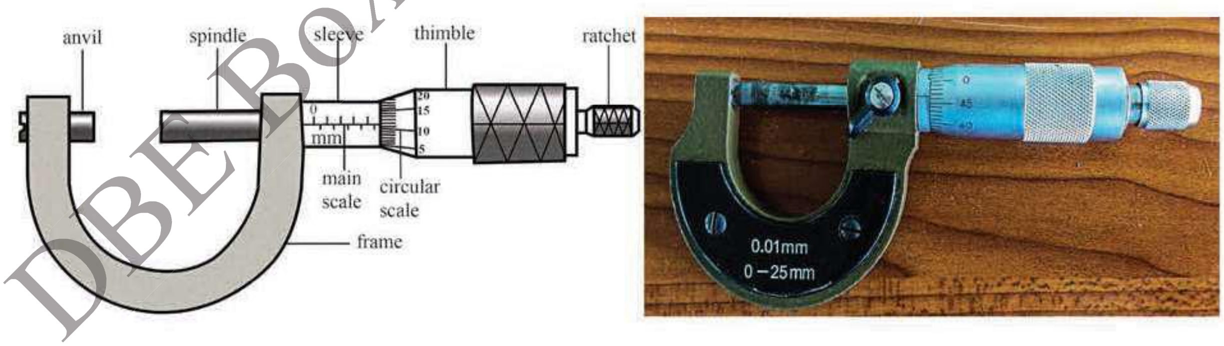

Figure 1.4 Screw gauge (Micrometer)

Table 1.3 Instruments used for length measurement and their accuracy

Length to be measured	Suitable instrument	Accuracy of instrument
several metres (m)	Measuring tape	1 mm (= 0.1 cm)
several centimetres (cm) to 1 m	Metre rule or half-metre rule	1 mm (= 0.1 cm)
between 1 cm and 10 cm	Vernier calipers	0.1 mm (= 0.01 cm)
less than 2 cm	Screw gauge (Micrometer)	0.01 mm (= 0.001 cm)

Key Words: accuracy, range

1.6 MEASUREMENT OF MASS

The mass of an object is a measure of the amount of matter in it.

Mass is measured in laboratories using a sliding mass balance or the electronic balance, as shown in Figure 1.5 and 1.6, respectively. The mass of an object can be found using balance like this.

The electronic balance is easier to use and also more accurate than sliding mass balance. The unknown mass is placed on the top of the pan and its mass is read directly from a display screen.

Figure 1.5 A sliding balance

Figure 1.6 An electronic balance

The balance really detects the gravitational pull on the object (weight), but the scale is marked to show the mass.
The mass of purified drinking water of 1 litre bottle is 1 kg.

1.7 MEASUREMENT OF TIME

Time is measured in years, months, days, hours, minutes and seconds, but the SI unit for time is the second (s). Most common modern clocks and watches depend on the vibration of quartz crystals to keep time accurately. The energy to keep these crystals vibrating comes from a small battery. A stopwatch (or) a stop clock shown in Figure 1.7(a) and (b) can be chosen to measure the time to an accuracy of a few tenths of a second. Digital stopwatches can measure up to 0.01 s as shown in Figure 1.7(c).

(a) Stopwatch (b) Stop Clock (c) Digital Stopwatch

[https://runnerclick.com/best-stopwatches-reviewed]

Figure 1.7 Time measuring instruments

SUMMARY

A **physical quantity** is the quantity that can be measured, and consists of a numerical magnitude and a unit.

Physical quantities can be classified as the **basic type** (length, mass, time, temperature,electric current, amount of substance, luminous intensity) and the **derived type** (area, volume, velocity, work, energy, etc.). Their units are also called the **basic units** and the **derived units.**

A derived unit is a unit of measurement formed by combining the basic (or base) units of a system.

Standard is something (or) a reference used as a measure for length, mass and time.

Unit is a quantity (or) an amount used as a standard of measurement.

EXERCISES

1. Is physics useful in the study of chemistry, biology and engineering subjects?
2. Determine the derived units of :
   (a) speed (= distance / time)
   (b) volume (= length × width × height)
   (c) density (= mass / volume)
3. The density of water is 1.0 g cm^{-3}. Convert this value to SI units.
4. Find the area of one page of a book whose dimensions are 20 cm × 25 cm in cm^2 and then convert this value to m^2.
5. Write down in powers of ten the values of the following quantities:
   (a) 60 nF (b) 500 MW (c) 20 000 mm (d) 400 μC

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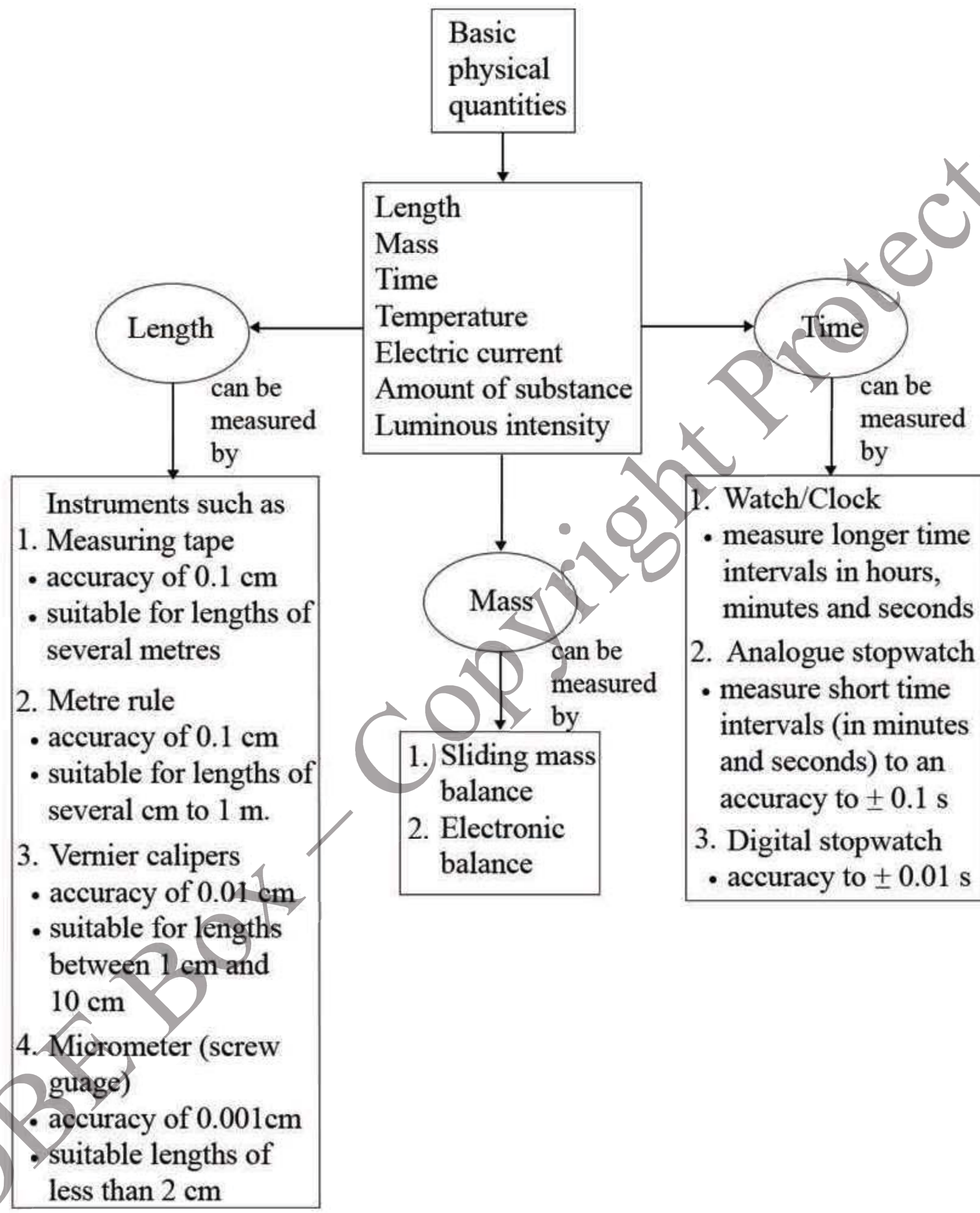
6. The thickness of a ream of printing paper is 5.2 cm. It contains 500 sheets of paper. What is the average thickness of one sheet of paper? Express your answer in SI unit.
7. The mass of 1 litre of water is 1 kg. Find the mass of 350 mL purified drinking water in a small-sized bottle.
8. The sun is a medium-sized star. In the Milky Way galaxy which includes the sun, there are one hundred billion stars. Write down this figure in the standard form. (1 billion = 10^9)
9. The tissue of a cell is 70 Å thick (Å = angstrom unit). If 1 Å = 10^{-10} m find the thickness of tissue in terms of an inch. (1 m = 39.4 in)
10. The size of elementary particles (which are also called the smallest particles) is of the order of $\sim 10^{-15}$ m and the size of the universe is of the order of $\sim 10^{26}$ m. Determine the ratio of the size of universe to the size of an elementary particle.
11. One acre is equal to 43 560 ft^2. How much is it in m^2? (1 ft = 0.305 m)
12. One litre is equivalent to 1 000 cm^3. How many litres are there in 231 in^3? (1in = 2.54 cm)
13. The shortest life-time of an elementary particle is 10^{-23} s and the age of the universe is 10^{18} s. Find the ratio of the two time intervals.
14. If the width of the Milky Way galaxy (which includes our solar system) is 10^5 *l*y, how long will a light signal take to travel that width?
15. According to observations and measurements, the farthest galaxies are at a distance of 10^{26} m from the earth. When space travel becomes highly advanced do you think that man will be able to visit those galaxies? (Light travels 3×10^8 m in one second and there are approximately 10^8 s in a year.)
16. The mass of an electron is $m_e = 9.1 \times 10^{-28}$ g. The mass of a muon is about $207m_e$ and the mass of a proton is about 1 836 m_e. Find the masses of muon and proton in kg. (Electron, muon and proton are the fundamental particles which are smaller than an atom.)

CONCEPT MAP


Basic physical quantities
Length
Mass
Time
Temperature
Electric current
Amount of substance
Luminous intensity
Length
can be measured by
Instruments such as
1. Measuring tape
• accuracy of 0.1 cm
• suitable for lengths of several metres
2. Metre rule
• accuracy of 0.1 cm
• suitable for lengths of several cm to 1 m.
3. Vernier calipers
• accuracy of 0.01 cm
• suitable for lengths between 1 cm and 10 cm
4. Micrometer (screw guage)
• accuracy of 0.001cm
• suitable lengths of less than 2 cm
Mass
can be measured by
1. Sliding mass balance
2. Electronic balance
Time
can be measured by
1. Watch/Clock
• measure longer time intervals in hours, minutes and seconds
2. Analogue stopwatch
• measure short time intervals (in minutes and seconds) to an accuracy to ± 0.1 s
3. Digital stopwatch
• accuracy to ± 0.01 s

CHAPTER 2

MOTION

This chapter introduces scalar and vector quantities and the manipulations of vectors; that is finding the sum and difference of two vectors and also resolving a vector into two perpendicular components. As motion is a fundamental part of physics, basic quantities associated with motion are also clearly defined and explained. The linear motion, the simplest type of motion, is studied together with the equations of motion under constant velocity and constant acceleration. Motion graphs, their interpretation and analysis are also included.

Learning Outcomes

It is expected that students will

- distinguish between a scalar quantity and a vector quantity.
- demonstrate correct use of vector symbols.
- find the sum and difference of two vectors and resolve a vector into two or more components.
- explain distance, displacement, speed, velocity and acceleration.
- study the equations of motion to analyze the motion under constant velocity and constant acceleration.
- illustrate and interpret motion graphs, namely, distance-time, speed-time graphs.
- solve problems demonstrating proper use of units, quantities and scientific notation for describing motion.

2.1 VECTORS

Scalar and Vector

Some physical quantities of physics are completely described by a single number (or magnitude) with an appropriate unit. Such quantities, that have only magnitude, are called scalar quantities. For example, it is sufficient to say that the length of the ship is 30 m, the mass of the block is 500 g and the area of the blackboard is 48 ft^2.

However, some quantities have a directional quality. Not only the magnitude but also the direction is required for the complete description of such quantities. For example, we have to say that the plane is flying with a velocity of 20 mi h^{-1} towards east, the force acting on the body is 20 N upwards and the displacement of the ship is 150 km northeast from the port. These quantities, that have both magnitude and direction, are called vectors. Since we have to come across vector quantities in most areas of physics, we need to study the addition, subtraction and resolution of vectors.

Vector Symbols

In printing, vectors are represented by boldface type, such as ***A, F, v, s.*** In handwriting, vectors are indicated by placing arrows on the top of their symbols. e.g. $\vec{A}$, $\vec{F}$, $\vec{v}$, $\vec{s}$. The magnitude of $\vec{F}$ is written as $|\vec{F}| = F$. We would use handwriting format to express vectors later in this chapter; that is, by placing arrows on top of their symbols.

Vector relations and their meanings

(i) $\vec{A} = \vec{B}$: $\vec{A}$ and $\vec{B}$ are equal in magnitude and have the same direction.

(ii) $\vec{A} = -\vec{B}$: $\vec{A}$ and $\vec{B}$ are equal in magnitude but have opposite directions.

(iii) $\vec{A} = 2\vec{B}$: The magnitude of $\vec{A}$ is two times the magnitude of $\vec{B}$ and the direction of $\vec{A}$ is the same as that of $\vec{B}$.

(iv) $\vec{A} = -3\vec{B}$: The magnitude of $\vec{A}$ is three times the magnitude of $\vec{B}$ and the direction of $\vec{A}$ is opposite to that of $\vec{B}$.

Graphical Representation of Vectors

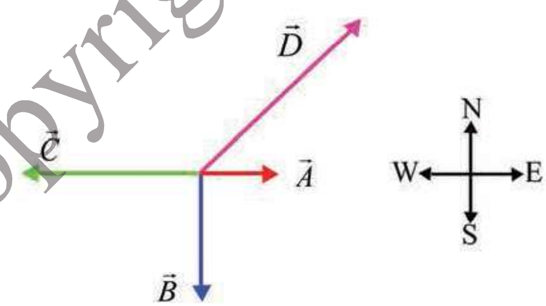
Using graphical method a vector may be represented by an arrow. The length of the arrow is proportional to the magnitude of the vector and the direction of the arrow gives the direction of the vector.

$\vec{A} = 5$ units (east)

$\vec{B} = 10$ units (south)

$\vec{C} = 15$ units (west)

$\vec{D} = 20$ units (north-east)



Addition of Two Vectors

To add $\vec{A}$ and $\vec{B}$, first draw $\vec{A}$.Then draw $\vec{B}$ in such a way that the tail of $\vec{B}$ is at the tip of $\vec{A}$. Then draw a third vector $\vec{R}$ from the tail of $\vec{A}$ to the tip of $\vec{B}$. $\vec{R}$ is the vector sum $\vec{A} + \vec{B}$ and it is called the resultant vector. It is to be noted that we can also draw $\vec{B}$ first, and then $\vec{A}$.

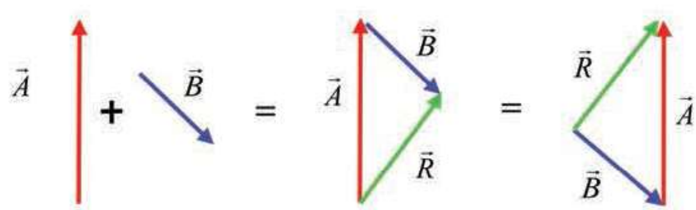


Figure 2.1 Diagram to illustrate vector addition

Subtraction of Two Vectors

In algebraic notation, $\vec{A} - \vec{B} = \vec{A} + (-\vec{B})$. Hence, vector subtraction is, in effect, vector addition. To subtract $\vec{B}$ from $\vec{A}$ (i.e. to find $\vec{A} - \vec{B}$), we add $\vec{A}$ and $(-\vec{B})$. Note that $(-\vec{B})$ has the same magnitude as $\vec{B}$ but its direction is opposite to that of $\vec{B}$.

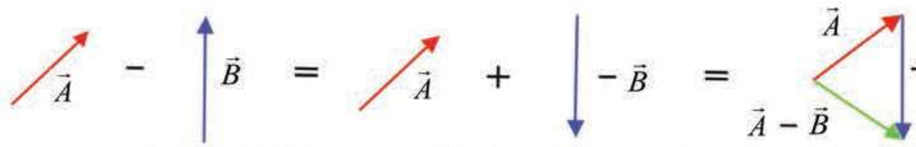


Figure 2.2 Diagram to illustrate vector subtraction

> $\vec{A} + \vec{B} = \vec{B} + \vec{A}$. Vector addition is commutative.
>
> $\vec{A} - \vec{B} = -(\vec{B} - \vec{A})$. Hence, vector subtraction is not commutative.

Example (1)

A boat travels east at 10 mi h^{-1} in a river that flows south at 3 mi h^{-1}. Find the boat's velocity relative to the river bank (the earth).

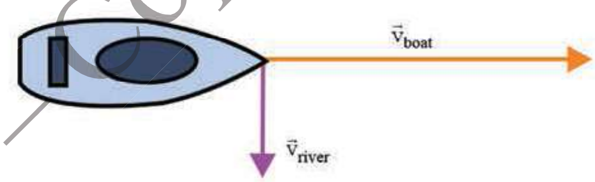
To find the boat's velocity relative to the river bank (the earth) we have to add the boat's velocity to the velocity of the river current.

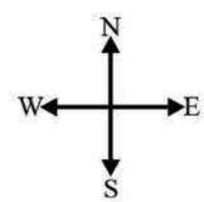
To find the magnitude of $\vec{v}$,

$$v^2 = (v_{\text{boat}})^2 + (v_{\text{river}})^2$$

$$= (10)^2 + (3)^2 = 109$$

$$v = 10.4 \text{ mi h}^{-1}$$

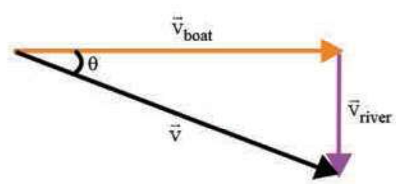




To find the direction,

$$\tan\theta = \frac{v_{river}}{v_{boat}} = \frac{3}{10} = 0.3$$

$$\theta = \tan^{-1}(0.3) = 17^{\circ}$$



The magnitude of the boat's velocity relative to the river bank = 10.4 mi h^{-1}

The direction = east 17° south (or 17° south of east).

Draw a scaled vector diagram and check your answer.

Resolution of a Vector into Two Perpendicular Components

Just as a number of vectors can be added to obtain a resultant vector, it is also possible to sub-divide a given vector into a number of different vectors. The process of sub-dividing a vector into two (or) more vectors is called resolution of a vector, and the new vectors obtained are called vector components of the original vector.

A useful application of vector resolution is sub-dividing a vector into two perpendicular components, namely, horizontal component and vertical component.

$\vec{A}$ = original vector

$\vec{A}_x$ = component of $\vec{A}$ along x-axis, x-component (or) horizontal component

$\vec{A}_y$ = component of $\vec{A}$ along y-axis, y-component (or) vertical component

$A_x = A\cos\theta$, $A_y = A\sin\theta$

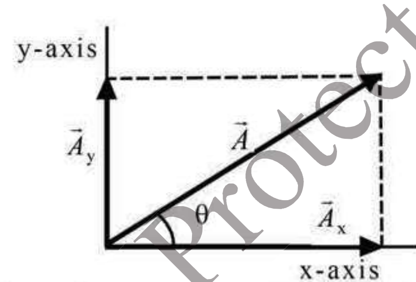


Figure 2.3 Components of a vector

Example (2)

A force of magnitude 5 N is inclined at an angle 37° to the horizontal. Find its horizontal and vertical components. ($\sin 37^\circ = 0.6$, $\cos 37^\circ = 0.8$)

$F = 5$ N, $\theta = 37^\circ$

horizontal component $F_x = F\cos\theta = 5\cos 37^\circ = 5 \times 0.8 = 4$ N

vertical component $F_y = F\sin\theta = 5\sin 37^\circ = 5 \times 0.6 = 3$ N

Reviewed Exercise

1. Given that $\vec{A}$ = 2 units (west) and $\vec{B}$ = 4 units (south), draw vector diagrams to carry out the following vector operations. (i) $\vec{A}+\vec{B}$ (ii) $2\vec{A}+\vec{B}$ (iii) $\vec{B}-\vec{A}$
2. A force 4 N, directed east, and a force 6 N, directed west, act on a particle. Find the magnitude and direction of the resultant force.

Key Words: scalar, vector, addition of vectors, resolution of a vector

2.2 DESCRIBING MOTION

Distance and Displacement

Consider that a particle moves from a starting point A to an end point B along a curved path as shown in Figure 2.4.

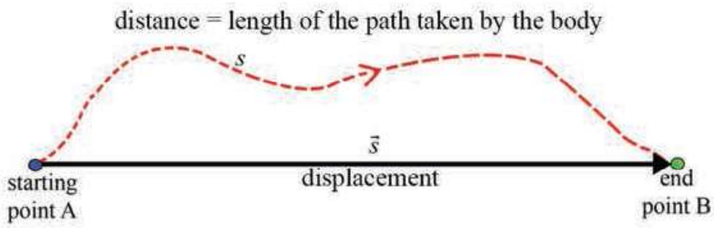


Figure 2.4 Distance and displacement of a body

Distance (or) distance travelled by the body is the length of the path along which the body moves. However, the displacement of the body is a vector directed from the starting point to the end point, as described in the diagram. Displacement is the distance travelled along a particular direction. Distance has no specific direction. It has only magnitude; and therefore, it is a scalar. On the other hand, displacement has a specific direction. It is always directed from the starting point to the end point. It has both magnitude and direction; and therefore, it is a vector.

Speed and Velocity

We can define speed and velocity from distance and displacement, respectively, as follows. Let us assume that, in Figure 2.4, the body moves from starting point A to end point B in a time interval t.

The average speed, v_{av} (or) $\bar{v}$, is the ratio of total distance s to time taken t.

$$v_{av} = \frac{s}{t} \quad \text{(or)} \quad \bar{v} = \frac{s}{t} \qquad (2.1)$$

The average velocity, $\vec{v}_{av}$ (or) $\bar{\vec{v}}$, is the ratio of total displacement $\vec{s}$ to time taken t.

$$\vec{v}_{av} = \frac{\vec{s}}{t} \quad \text{(or)} \quad \bar{\vec{v}} = \frac{\vec{s}}{t} \qquad (2.2)$$

If the starting point and the end point are the same, the total displacement is zero. Therefore, average velocity is zero.

Now we would like to introduce the concept of instantaneous speed and instantaneous velocity.

The speed and velocity which represent a motion for a certain period of time interval are called average speed and average velocity, whereas, the speed (or) velocity at a particular instant of time are referred to as instantaneous speed and instantaneous velocity. Note that the speedometer of a car indicates the instantaneous speed of the car.

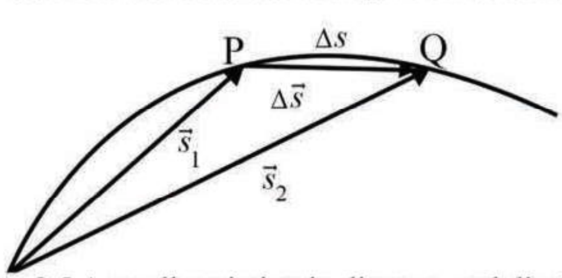


Figure 2.5 A small variation in distance and displacement

In Figure 2.5, a body moves from P to Q in a small interval of time Δt. The corresponding distance travelled is Δs (arc PQ) and the displacement is $\Delta \vec{s}$. Then, the instantaneous speed and instantaneous velocity are defined as the limiting values of $\frac{\Delta s}{\Delta t}$ and $\frac{\Delta \vec{s}}{\Delta t}$ as time Δt approaches zero. It is the limiting case when P and Q coincides.

Instantaneous speed $$v = \lim_{\Delta t \to 0} \frac{\Delta s}{\Delta t} = \frac{\mathrm{d}s}{\mathrm{d}t} \qquad (2.3)$$

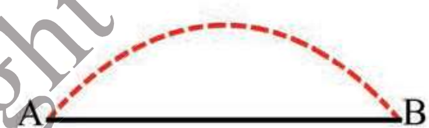
Instantaneous velocity $$\vec{v} = \lim_{\Delta t \to 0} \frac{\Delta \vec{s}}{\Delta t} = \frac{\mathrm{d}\vec{s}}{\mathrm{d}t} \qquad (2.4)$$

These limiting values are known as the time rate of change of corresponding quantities (s and $\vec{s}$).

The instantaneous speed is defined as the time rate of change of distance and the instantaneous velocity is defined as the time rate of change of displacement.

Example (3)

(a) A body travels from A to B along a straight line and another body travels from A to B along a curve (shown by the dotted line). If the straight-line distance between A and B is 3 km, find the displacement of each body.



(b) The first body moves along the straight line from B back to A. The second body moves along the curved-path back to the same starting point A. What are the displacements of two bodies now? If the first body takes 2 h to travel from A to B, what will be its velocity?

(a) Since the starting point is A and the end point is B for both bodies, the displacement of each body is 3 km, directed from A to B. However, the distance travelled by each body is different.

(b) When both bodies get back to A, the displacement of each body is zero as the starting point as well as the end point is A for both bodies.

$$s = 3\,\text{km},\ t = 2\,\text{h}$$

The velocity (i.e. average velocity) of first body is

$$v_{av} = \frac{s}{t} = \frac{3}{2} = 1.5\ \text{km h}^{-1}$$

$$= \frac{3 \times 1\,000}{2 \times 3\,600} = 0.42\ \text{m s}^{-1} \text{ directed from A to B.}$$

Acceleration

When a body is moving along a straight line with a constant speed, the velocity of the body is also constant because its magnitude and direction remain constant. For a motion with constant velocity equal displacements take place in equal intervals of time. Motion with constant velocity is known as uniform motion.

If either magnitude (or) direction (or) both magnitude and direction of the velocity changes, the body is said to have an acceleration $\vec{a}$. Motion with changing velocity is called non-uniform motion (or) accelerated motion.

If the velocity of a body changes from initial velocity $\vec{v}_0$, to final velocity $\vec{v}$, in a time interval t, the average acceleration $\vec{a}_{av}$ is defined by the equation, $\vec{a}_{av} = \dfrac{\vec{v} - \vec{v}_0}{t}$.

It is the ratio of the change in velocity to the time taken. As in the cases of instantaneous speed and instantaneous velocity, instantaneous acceleration can also be defined as

$$\vec{a} = \lim_{\Delta t \to 0} \frac{\Delta \vec{v}}{\Delta t} = \frac{\mathrm{d}\vec{v}}{\mathrm{d}t} .$$

Instantaneous acceleration $\vec{a} = \lim_{\Delta t \to 0} \dfrac{\Delta \vec{v}}{\Delta t} = \dfrac{\mathrm{d}\vec{v}}{\mathrm{d}t}$ (2.5)

Instantaneous acceleration is the time rate of change of velocity.

Acceleration is said to be positive if the magnitude of velocity is increasing and negative if the magnitude of velocity is decreasing. Negative acceleration is usually called deceleration or retardation.

Reviewed Exercise

1. Define average velocity and instantaneous velocity.
2. Define speed and velocity such that the two may be distinguished.

Key Words : average speed, instantaneous velocity, average velocity, constant velocity

2.3 EQUATIONS OF MOTION

(i) Linear Motion with Constant Velocity

Motion along a straight line is called linear motion. It is the simplest type of motion which can be encountered in many cases. In a linear motion, the magnitude of the displacement is equal to the distance moved. The magnitude of the velocity is also equal to the speed. The most simplest type of motion is the linear motion with constant velocity (uniform motion). Since the velocity is constant, the acceleration is zero. As the body is moving with a non-varying velocity, the instantaneous velocity and average velocity are the same.

We can use equations of motion in calculating the problems of motion. These equations relate the previously mentioned physical quantities associated with motion. In describing the equations of motion we shall not use the vector notation, i.e., we will omit the arrows on the symbols as the direction of motion is already fixed. However, we will use positive (+) and negative (–) signs to describe the two opposite directions along a straight line.

The equation of motion for a linear motion with constant velocity is $v = \dfrac{s}{t}$, where v = constant velocity, s = displacement and t = time taken.

(ii) Linear Motion with Constant Acceleration

If the rate of change of velocity is constant, i.e., the velocity of a body changes at a constant rate, then the acceleration is said to be constant. For example, if a body is moving with a constant acceleration of 5 m s^{-2}, the velocity of the body changes by 5 m s^{-1} in every second. Since the acceleration is constant, the instantaneous acceleration and average acceleration are the same.

Suppose that a body moving along a straight line with a constant acceleration $\vec{a}$ changes its velocity from $\vec{v}_0$ to $\vec{v}$ in a time interval t and traverses a displacement $\vec{s}$.

We are now going to express the equations of motion for this case. As described previously, we are not going to use the vector notation. These equations are:

$$v = v_0 + a\,t \qquad (2.6)$$
$$v^2 = v_0^2 + 2\,a\,s \qquad (2.7)$$
$$s = v_0\,t + \tfrac{1}{2}\,a\,t^2 \qquad (2.8)$$
$$s = \bar{v}\;t \qquad (2.9)$$
$$\bar{v} = \frac{v_0 + v}{2} \qquad (2.10)$$

where v_0 = initial velocity, v = final velocity
$\bar{v}$ = average velocity
a = acceleration
s = displacement
t = time taken

Note that except Eq.(2.7), the rest equations can be expressed in vector form.
In the above equations, Eq.(2.6), Eq.(2.9) and Eq.(2.10) have their own physical significance, where as Eq.(2.7) and Eq.(2.8) are derived from Eqs. (2.6), (2.9) and (2.10) as shown below.

$$s = \bar{v}\;t = \left(\frac{v_0 + v}{2}\right) t$$
$$= \left(\frac{v_0 + v_0 + a\,t}{2}\right) t$$
$$= v_0\,t + \tfrac{1}{2}\,a\,t^2$$

$$s = \bar{v}\;t = \left(\frac{v_0 + v}{2}\right)\left(\frac{v - v_0}{a}\right)$$
$$= \frac{v^2 - v_0^2}{2\,a}$$
$$v^2 = v_0^2 + 2\,a\,s$$

Table 2.1 Units of displacement, velocity and acceleration

Quantity	MKS / SI	CGS	FPS
displacement /distance	m	cm	ft
velocity/speed	m s^{-1}	cm s^{-1}	ft s^{-1}
acceleration	m s^{-2}	cm s^{-2}	ft s^{-2}

m = metre, m s^{-1} = metre per second, m s^{-2} = metre per second square

Example (4)

A car is travelling with a constant velocity of 6 m s^{-1}. The driver applies the brakes as he sees a cow which is at a distance of 24 m from the car. Find the acceleration of the car if it stops just in front of the cow.

initial velocity $v_0 = 6$ m s^{-1}, final velocity $v = 0$, displacement (or distance moved) $s = 24$ m, acceleration $a = ?$

$$v^2 = v_0^2 + 2as$$

$$0 = (6)^2 + 2 \times a \times 24$$

$$a = -0.75 \text{ m s}^{-2}$$

Acceleration is negative because the velocity decreases with time.

Example (5)

A car starting from rest travels with a uniform acceleration of 2 m s^{-2} in the first 6 s. It then travels with a constant velocity for half an hour. Find the distance travelled in the first 6 s as well as the distance travelled in the following half an hour.

For the first part of motion,

initial velocity $v_0 = 0$, acceleration $a = 2$ m s^{-2}, time taken $t = 6$ s,

distance travelled $s = ?$

$$s = v_0 t + \tfrac{1}{2} a t^2$$

$$= 0 + \tfrac{1}{2} \times 2 \times (6)^2 = 36 \text{ m}$$

velocity after 6 s is

$$v = v_0 + at$$

$$= 0 + 2 \times 6 = 12 \text{ m s}^{-1}$$

For the second part of motion,

constant velocity $v = 12$ m s^{-1}, time taken $t = 30$ min = 1 800 s, distance travelled $s = ?$

$$s = vt$$

$$= 12 \times 1\,800 = 21\,600 \text{ m} = 21.6 \text{ km}$$

Reviewed Exercise

- Is the formula for average velocity $\overline{v} = \dfrac{v_0 + v}{2}$ always true?

Key Words : uniform motion, constant accelerated motion

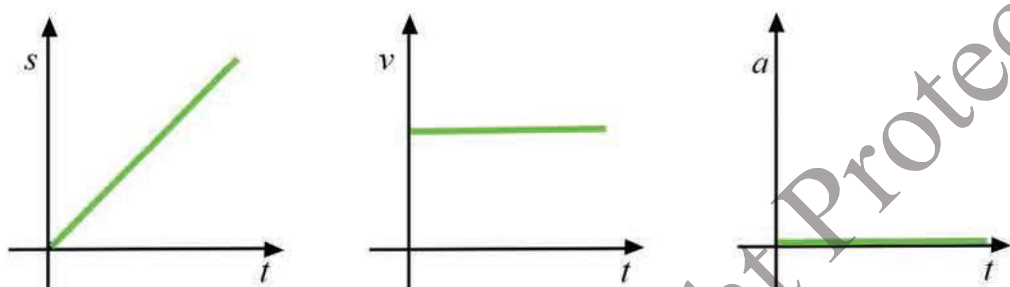
2. 4 MOTION GRAPHS

Motion can also be described (or) analyzed conveniently with the help of graphs. The motion graphs are of three types:

(i) displacement-time graph (*s-t* graph),
(ii) velocity-time graph (*v-t* graph) and
(iii) acceleration-time graph (*a-t* graph).

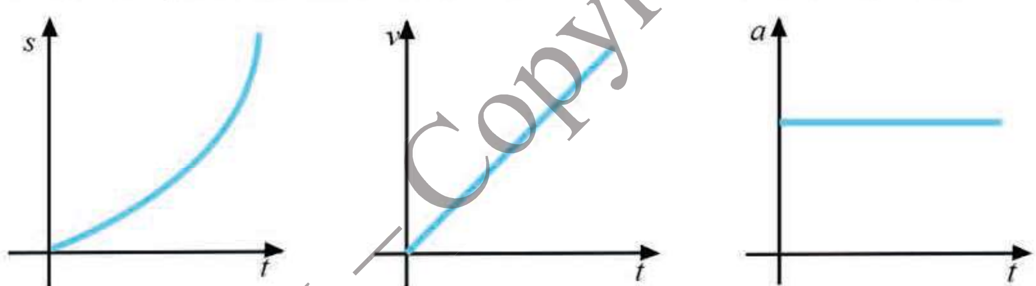
(i) Motion Graphs for a Linear Motion with Constant Velocity (a = 0)

s-t graph *v-t* graph *a-t* graph

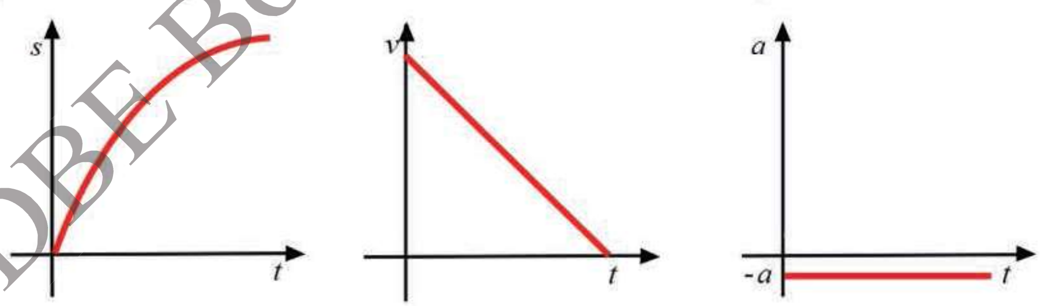


The slope of the *s-t* graph gives the constant velocity.

(ii) Motion Graphs for a Linear Motion with Constant Positive Acceleration



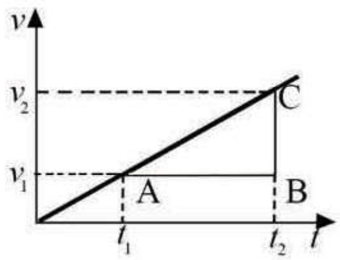
(iii) Motion Graphs for a Linear Motion with Constant Negative Acceleration

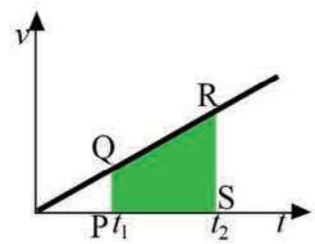


Of three types of motion graphs, *v-t* graph is very useful to analyze a motion.

(i) The slope of a *v-t* graph gives the acceleration of a body.

(ii) The area under a *v-t* graph gives the displacement (or) distance moved by the body.





acceleration a = slope of AC

$$= \frac{CB}{BA} = \frac{v_2 - v_1}{t_2 - t_1}$$

displacement s = distance travelled between t_1 and t_2

= area of PQRS

Example (6)

A train starts from station A, with an acceleration of 0.2 m s^{-2} and attains its maximum speed in 1.5 min. After continuing at this speed for 4 min it is uniformly retarded for 45 s before coming to rest in station B. Find by drawing a suitable graph: (a) the distance between A and B in km, (b) the maximum speed in km h^{-1}, (c) the average speed in m s^{-1}, (d) acceleration during the last stage of motion.

For the first part of motion,
initial velocity $v_0 = 0$, acceleration $a = 0.2$ m s^{-2}, time taken $t = 1.5$ min = 90 s,
velocity after 1.5 min, v = ?

$$v = v_0 + a\,t = 0 + 0.2 \times 90 = 18 \text{ m s}^{-1}$$

(a) the distance between A and B in km

s = area OPQR = area OPN + area PQMN + area MQR

= (½ ON × NP) + (NP × NM) + (½ × MR × MQ)

= (½ × 90 × 18) + (18 × 240) + (½ × 45 × 18) = 810 + 4 320 + 405 = 5 535 m

= 5.535 km

(b) the maximum speed in km h^{-1}

$$v = 18 \text{ m s}^{-1} = \frac{18/1\,000}{1/3\,600} \text{ km h}^{-1} = \frac{18 \times 3\,600}{1\,000} \text{ km h}^{-1} = 64.8 \text{ km h}^{-1}$$

(c) the average speed in m s^{-1}

$$\overline{v} = \frac{s}{t} = \frac{5\,535}{375} = 14.76 \text{ m s}^{-1}$$

(d) acceleration during the last stage of motion

$$a = \text{slope of QR} = \left(\frac{QM}{MR}\right) = \frac{0-18}{375-330} = \left(\frac{-18}{45}\right) = -0.4 \text{ m s}^{-2}$$

The negative sign indicates that the slope is negative. That is, it is a negative acceleration (or) retardation.

Reviewed Exercise

- How can the magnitude of displacement be determined from v-t graph?

SUMMARY

Distance (or) distance travelled by the body is the length of the path along which the body moves.

Displacement is the distance travelled along a particular direction.

The average speed is the ratio of total distance to time taken.

The average velocity is the ratio of total displacement to time taken.

The instantaneous speed is defined as the time rate of change of distance.

The instantaneous velocity is defined as the time rate of change of displacement.

The average acceleration is the ratio of the change in velocity to the time taken.

The instantaneous acceleration is defined as the time rate of change of velocity.

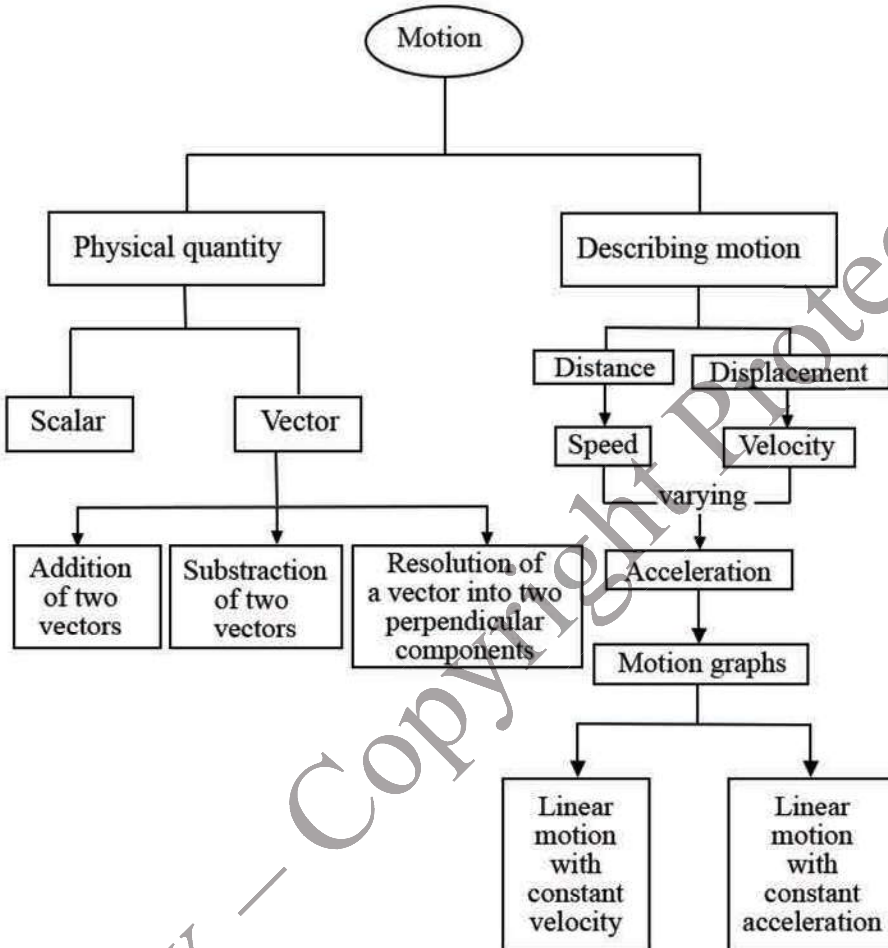
EXERCISES

1. Which of the following quantities are scalars and which are vectors?
   (a) speed (b) velocity (c) average velocity (d) acceleration (e) displacement.
2. Given that $\vec{A} = 3$ units (east) and $\vec{B} = 4$ units (north), draw vector diagrams to carry out the following vector operations. (i) $\vec{A}+\vec{B}$ (ii) $2\vec{A}+\vec{B}$ (iii) $\vec{A}-\vec{B}$ (iv) $\vec{B} - \vec{A}$.
3. A force 3 N pointing east and a force 6 N pointing north acts on a particle. Find the magnitude of the resultant force. Check your answer by drawing a vector diagram.
4. A vector of magnitude 5 units is inclined at an angle 37° to the x-axis and another vector of magnitude 10 units is inclined at 53° to the x-axis. What is the magnitude of the sum of the vector components (i) along the x-axis, (ii) along the y-axis? ($\sin 37^\circ = \cos 53^\circ = 0.6$, $\sin 53^\circ = \cos 37^\circ = 0.8$)
5. A person goes from his house to a nearby shop at the corner of the street and returns home. Can you say that the distance travelled by him is equal to the magnitude of his displacement? Explain.
6. In a one-round-about-town walking race the starting point is the same as the finishing point. Whose magnitude of displacement is greater: the one who completes the race (or) the one who gives up half-way?
7. Check whether the following statements are true or not.
   (a) If the speed changes, the velocity also changes.
   (b) Although speed changes, there is no acceleration.
   (c) If the speed does not change, but the direction changes, there will be acceleration.

8. In a 400 m race, the person running in the innermost lane clocked 50 s and won the gold medal. Find his average velocity. Is the magnitude of the average velocity the same as the value of the average speed? (Hint: For the innermost lane, the starting point is the same as the finishing point.)
9. A man walks 3 miles east and then 3 miles north. Draw a vector diagram to show his resultant displacement from his starting point. If he takes 2 hours to completes his journey, find his average speed and average velocity.
10. A car moving on a straight road with constant acceleration arrives at a certain point after travelling 5 s from the starting point. If the initial velocity is 44 ft s^{-1} and the final velocity is 66 ft s^{-1}, find the acceleration and average velocity of the car. How far has it travelled during this 5 s?
11. A plane starts from rest , speeds over a distance of 450 m with constant acceleration for 15 s and takes off. What is the acceleration of the plane? Find its take-off velocity in km h^{-1}.
12. A car moving with a speed of 108 km h^{-1} stops in 15 s due to a uniform acceleration. Find the value of the acceleration.
13. An object moves with an initial velocity of 5 m s^{-1}. After 10 s its velocity is 10 m s^{-1}. If the object moves with constant acceleration in a straight line, find (a) its average velocity, (b) the distance travelled in 10 s and (c) its acceleration.
14. A particle with an initial velocity of 10 m s^{-1} travel in a straight line and stops completely after 12 s. Find the uniform acceleration of the particle. How far has the particle travelled before coming to rest?
15. A body starts from rest and accelerates at 3 m s^{-2} for 4 s. Its velocity remains constant at the maximum value so reached for 7 s and finally comes to rest with uniform negative acceleration after another 5 s. Use a graphical method to find each of the following : (a) the distance moved during each stage of motion, (b) the average velocity over the whole period.
16. Draw a graph of velocity against time for a body which starts with an initial velocity of 4 m s^{-1} and continues to move with an acceleration of 1.5 m s^{-2} for 6 s. Show how you would find each of the following from the graph: (a) the average velocity, (b) the distance moved in those 6 s.
17. A car is travelling with a constant velocity of 36 km h^{-1}. The driver sees a cow on the road at a distance 28 m from the current position. If the car decelerates at 2 m s^{-2}, will the car hit the cow?
18. Motion of an object is recorded as shown in the table below. (i) Draw the distance-time graph plotting time along the x-axis, (ii) Find the speed of the object.

time / s	0	1	2	3	4	5
distance / m	0	4	8	12	16	20

CONCEPT MAP


Motion
Physical quantity
Describing motion
Scalar
Vector
Distance
Displacement
Speed
Velocity
varying
Addition of two vectors
Substraction of two vectors
Resolution of a vector into two perpendicular components
Acceleration
Motion graphs
Linear motion with constant velocity
Linear motion with constant acceleration

CHAPTER 3

FORCES

The physics describing motion, called kinematics, was discussed in the previous chapter. This chapter is dealt with dynamics which explains motion in relation to the physical factors that affect motion such as force, momentum, mass etc. A fundamental concept in dynamics is force. Force can change the state of motion of an object. Note that forces do not always cause motion.

Learning Outcomes

It is expected that students will

- describe concept of inertia.
- explain force as a cause for change of state of motion.
- recognize gravitational force between two masses which obeys inverse square law.
- distinguish between mass and weight.
- classify different kinds of forces.
- examine momentum and the application of the law of conservation of momentum.
- determine the characteristics of the freely falling bodies.
- demonstrate basic knowledge and skill related to gravitational force and frictional force.
- use mathematical relationships to solve problems and predict events.

Although a force is commonly understood as a push (or) a pull, it cannot be said that this definition is sufficient and complete. In order that the meaning of force be more complete and exact, the definition must be modified. Force is defined precisely by Newton's laws of motion. In this chapter, force concept and the relation between force and acceleration will be presented and discussed.

3.1 NEWTON'S LAWS OF MOTION

Firstly, Newton's three laws of motion will be stated in words and then expressed in mathematical forms.

First Law

Newton's first law states that:

When no net external force acts upon it, a particle at rest will remain at rest and a particle in motion at a constant velocity will continue to move with the same constant velocity.

In mathematical form, If $\vec{F}_{net} = 0$ then $\vec{a} = 0$, $\vec{v} =$ constant (or) zero (3.1)

This law means that if no net external force acts on a particle, the initial state of the motion of the particle will not be changed.

For example, if two equal and opposite forces act simultaneously on a particle at rest, it will remain at rest. In this case, the net force acting on the particle is zero since the two forces cancel out. Therefore, the initial state of the particle is totally unchanged. Another statement of the first law, if there is no net external force of any kind, a particle initially in motion at a constant velocity will continue to remain in the same state of motion. Again, although external forces are simultaneously acting on a particle, if the resultant of the applied forces is zero, the initial state of the particle will not be changed. It is more correct to say 'force changes the states of motion' rather than to say 'force causes motion'. This is one property of force.

Newton's first law expresses the idea of inertia. Inertia is the natural property of a body which resists the change of its state of motion. The inertia of a body is its reluctance to start moving, and its reluctance to stop once it has begun moving. In fact, the first law is often referred as the law of inertia.

Second Law

Newton's second law predicts what will happen when a net force acts on a particle. Its velocity will change. It will accelerate. More precisely the second law states that:
The net external force acting upon a particle is equal to the product of the mass and the acceleration of particle.

In mathematical form, $\vec{F}_{\text{net}} = m\vec{a}$ (3.2)

In the above equations $\vec{F}_{\text{net}}$ is the net external force. The direction of the acceleration is the same as that of the net force.

The second law may also be viewed as follows:

If a net external force acts upon a particle, the force produces acceleration, and the ratio of the force to the acceleration is the mass of the particle.

Let us consider a particle. Assume that a force $\vec{F}_1$ produces an acceleration $\vec{a}_1$ when applied to the particle, and a force $\vec{F}_2$ applied to the same particle produces an acceleration $\vec{a}_2$ as shown in Figure 3.1.

Hence, according to Newton's second law we have

$$\frac{\vec{F}_1}{\vec{a}_1} = \frac{\vec{F}_2}{\vec{a}_2} = m = \text{constant} \qquad (3.3)$$

where the constant m is the mass of the particle. If $F_2 > F_1$ then $a_2 > a_1$, it means that as the magnitude of the force acting on a particle increases, the acceleration of the particle will increase accordingly. It is equivalent to say that acceleration is directly proportional to force.

In symbols, $\vec{a} \propto \vec{F}$

Therefore, second law is also called law of force and acceleration.

Figure 3.1 Illustration for net force and accleration

Third Law

Newton's third law of motion states that:
Whenever two particles interact, the force exerted by the second on the first is equal in magnitude and opposite in direction to the force exerted by the first on the second.

In other words, for every action, there is an equal and opposite reaction.

$$\vec{F}_{\text{second on first}} = -\vec{F}_{\text{first on second}} \qquad (3.4)$$

In order to discuss and explain Newton's third law the following cases will be considered. Consider a man sitting on a chair. The man exerts a force which is equal to his body weight on the chair. At the same time the chair exerts a reaction force, which is equal in magnitude and opposite in direction, on the man. If the force exerted by the man is called 'action', the force exerted by the chair should be called 'reaction' shown in Figure 3.2.

As another case consider a man firing a gun at a target. The gun exerts a force on the bullet, and the bullet exerts an equal and opposite reaction force on the gun. This gives rise to a recoil force to the shoulder. The two forces are equal in magnitude but opposite in direction as shown in Figure 3.3.

Figure 3.2 Action and reaction force for sitting on chair

Figure 3.3 Action and reaction force for firing a gun

In each of the above cases action and reaction act as a pair at the same time but the pair of forces acts on two separate objects.

Important facts relating to force which arise from Newton's third law are as follows:

- It is not a single force acting by itself but a pair of forces acting simultaneously.
- This pair of forces is action - reaction pair. Action - reaction pair does not act on a single object but acts on two separate objects.
- Action force and reaction force cannot cancel out each other.

According to these observations the third law is also known as law of action and reaction.

Units of Force

Units of force can now be defined explicitly from $F = ma$. The newton and the dyne are particularly useful units of force. In SI units, force that is acting on 1 kg mass to give it an acceleration of 1 m s^{-2} is called 1 newton (1 N). 1 N = 1 kg m s^{-2}

Similarly, in CGS system a force that is acting on 1 g mass to give it an acceleration of 1 cm s^{-2} is called 1 dyne. 1 dyne = 1 g cm s^{-2} (1 N = 10^5 dynes)

In FPS system the unit of force is pound (lb).The slug is the unit of mass in British engineering system. It is defined as follows: when 1 pound force acts on a body and the acceleration of the body is 1 ft s^{-2}, the mass of the body is called 1 slug. 1 lb = 1 sl ft s^{-2}

Example (1) If 10 N force acts upon a 2 kg mass, find the acceleration produced.

Since F = 10 N and m = 2 kg, using Newton's second law,

$$F = ma$$
$$10 = 2 \times a$$
$$a = 5 \text{ m s}^{-2}$$

Example (2) A 12 lb force gives a body an acceleration of 4 ft s^{-2}. Find the mass of the body.

Since F = 12 lb and a = 4 ft s^{-2}, using Newton's second law,

$$F = ma$$
$$12 = m \times 4$$
$$m = 3 \text{ sl}$$

Example (3) A 2 kg ball is moving with an initial speed of 15 m s^{-1} on a rough plane which is in a horizontal position, and gradually slows down and stops after travelling 20 m. Find the magnitude of the force which resists the motion of the ball.

The speed of the ball changes from 15 m s^{-1} to 0 m s^{-1} after travelling 20 m. Thus, acceleration of the ball is;

$$v^2 = v_0^2 + 2as$$
$$0 = (15)^2 + 2a \times 20$$
$$0 = 225 + 40a$$
$$a = \frac{-225}{40} = -5.6 \text{ m s}^{-2}$$

Using Newton's second law, the force resisting the motion of the ball is,

$$F = m\,a$$
$$= 2 \times (-5.6) = -11.2 \text{ N}$$

The minus sign indicates that the direction of the force is opposite to that of the motion of the ball. The magnitude of the force is 11.2 N.

Reviewed Exercise

1. Is it correct to describe Newton's second law in symbols as $\vec{F} \propto \vec{a}$?
2. Although two forces act simultaneously on a body, it continues to move with a constant velocity. What can be said about the two forces?
3. Can action and reaction cancel each other? Why?

Key Words : inertia, net external force, action and reaction

3.2 GRAVITATIONAL FORCE AND NEWTON'S LAW OF GRAVITATION

Newton was able to point out and express precisely that all bodies in the universe are attracting one another. Gravitational force causes bodies which are above the earth's surface to fall onto the earth's surface. The gravitational force enables the moon to go round the earth and the earth to go round the sun. These are examples of the effects of gravitational force.

Newton stated the gravitational law as follows:

Everybody attracts every other body in the universe. The gravitational force between the two bodies is directly proportional to the product of the masses and inversely proportional to the square of the distance between them.

In symbols, $$F \propto \frac{m_1 m_2}{r^2}$$

where F is the gravitational force between the masses m_1 and m_2 whose distance apart is r as shown in Figure 3.4.

$$F = G\frac{m_1 m_2}{r^2} \qquad (3.5)$$

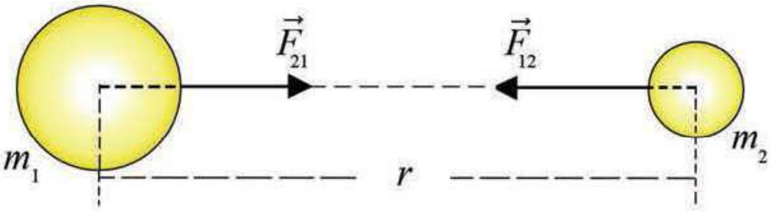


Figure 3.4 The gravitaional force between two bodies

$\vec{F}_{12}$= gravitational force exerted by the first body on the second

$\vec{F}_{21}$= gravitational force exerted by the second body on the first

$\hat{r}_{21}$ = unit vector directed from the second body to the first

Unit vector is a vector that has the magnitude 1.

$$\hat{r}_{21} = \frac{\vec{r}_{21}}{r_{21}}$$

If the Newton's law of gravitation is expressed as an equation in vector notation;

$$\vec{F}_{21} = -\frac{Gm_1m_2}{r_{21}^2}\ \hat{r}_{21} \qquad (3.6)$$

where G is a constant which is the same for all bodies in the universe.

According to experimental measurements the value of G in MKS system is found to be 6.67×10^{-11} $m^3\,kg^{-1}\,s^{-2}$ (or) $N\,m^2\,kg^{-2}$.

Applications of Newton's law of gravitation

(a) The attractions of the moon and the sun upon water of the earth cause tides.

(b) Satellites are kept in their circular orbit by the gravitational attraction of the earth.

Reviewed Exercise

- Express the value of G in the CGS units.

Key Words : gravitational force, gravitational constant

3.3 DIFFERENT KINDS OF FORCES

Four fundamental forces in nature are all field forces. They are the gravitational force, weak force, electromagnetic force and nuclear force. Nuclear force is the strongest and the gravitational force is the weakest of these forces. The electromagnetic force is the second strongest force. Among the four forces the gravitational and the electromagnetic forces are long-range forces and the remaining two forces are short-range forces.

The gravitational force acts between objects. The electromagnetic force acts between electric charges. Weak force acts between subatomic particles. Strong nuclear force acts between elementary particles such as proton, neutron, pion and strange particles.

In the study of mechanics, apart from gravitational force, frictional force and elastic force will also be encountered. However, unlike gravitational force, these two mechanical forces are not fundamental forces. When a spring is stretched (or) a plastic ruler is bent, the force that causes the spring and the ruler to retain their original form is called elastic force. When a body is placed on a floor, the bottom part of the body and the surface of the floor are in contact, and there is a force, between the two surfaces which resists the motion of the body. The force that acts to resist the motion of the body is frictional force. The frictional force depends on the smoothness and cleanliness of the surfaces, the force pressing the two surfaces together and the speed of the body.

Key Words : fundamental forces, long-range forces, short-range forces, frictional force, elastic force

3.4 MASS AND WEIGHT

If a body is dropped from a height above the surface of the earth, it will fall onto the ground. This is due to the force of gravity. The weight of body is the force of gravity acting on it which gives its acceleration when it is falling. The acceleration due to the gravitational force is called acceleration due to gravity and it is represented by the symbol g (9.8 m s^{-2} or 9.8 N kg^{-1}). In FPS system, $g = 32$ ft s^{-2} .

The attracting force of the earth acting on a body is defined as the weight of the body. Let the mass of the body be m; and if $a = g$ is substituted in Newton's second law: $F = m\ a$, the gravitational force acting on the body (or) the weight of the body is found to be

$$w = m\ g \tag{3.7}$$

This relation is true not only for freely falling bodies but also for bodies on the ground. Weight is a vector and is directed toward the center of the Earth.

> Since weight is force, units of weight are newton, dyne and pound while the units of mass are kilogram, gram and slug.

Mass is the quantity of matter in a body. Mass is also a measure of inertia. The mass of a body measures its inertia. The mass of a body defined from this point of view is called inertial mass while the mass defined by $m = \dfrac{w}{g}$ is called gravitational mass. Mass should not be confused with weight. Mass and weight are two different quantities. Mass is a scalar and always a constant. Wherever a body may be, there is no change in the value of the mass of the body. But the weight of the body can change.

Example (4) If $G = 6.67 \times 10^{-11}$ m^3 kg^{-1} s^{-2}, mass of the earth, $M = 5.97 \times 10^{24}$ kg and radius of the earth, $R = 6.37 \times 10^6$ m, find the value of the acceleration due to gravity g.

Consider the mass of a body at the earth's surface as m. The distance, r from the body to the centre of the earth is just the radius of the earth R. The gravitational force acting on the body is $F = G\dfrac{mM}{r^2} = G\dfrac{mM}{R^2}$.

According to the definition of the weight of the body, this gravitational force is the weight of the body mg.

$$G\frac{mM}{R^2} = mg$$

$$g = G\frac{M}{R^2}$$

Note that the value of g is independent of the properties of the body. The value of g near the earth's surface is $g = 6.67 \times 10^{-11} \times \dfrac{5.97 \times 10^{24}}{\left(6.37 \times 10^6\right)^2} = 9.8$ m s^{-2} (or) 9.8 N kg^{-1}.

Reviewed Exercise

- The weight of a body may change when its location is changed, but mass does not. Why?

Key Words : acceleration due to gravity, weight, inertial mass, gravitational mass

3.5 FREELY FALLING BODIES

If a body is dropped from a height near the earth's surface, the body will fall onto the ground with a constant acceleration g. If the air resistance is neglected, the fall of the body is defined as free fall. Equation of motion under constant acceleration described in chapter 2 can be used in the free fall. In these equations we will use the symbol h for displacement s and g for acceleration a. Hence, the equations become

$$v = v_0 + g\,t \qquad (3.8)$$

$$v^2 = v_0^2 + 2g\,h \qquad (3.9)$$

$$h = v_0 t + \frac{1}{2} g\,t^2 \qquad (3.10)$$

Note that the acceleration due to gravity g is directed downwards (towards the centre of the earth) and it varies only slightly from one place to another, and therefore, its value is assumed to be constant in the calculations.

> In solving the free fall problems we are going to use one dimensional coordinate system with its origin taken as the initial position of the body under consideration. We have to introduce + and – signs for the quantities involved in Eq (3.8) to Eq (3.10). That is, displacement h will be positive if it is above the origin and negative below the origin. Velocities v_0 and v will be positive if they are directed upward and negative if directed downward. Since acceleration g is always directed downwards its value will be negative (i.e. $g = -9.8\ \text{m s}^{-2}$).

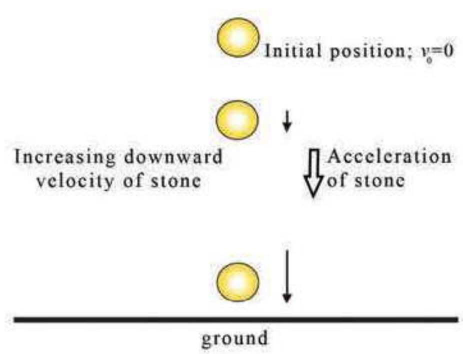
These sign conventions (positive and negative) are easily understandable as described in the following examples.

Example (5) What is the velocity of a stone freely falling from a height of 20 m when it strikes the ground? How long does the stone take to reach the ground? (Assume that $g = 10\ \text{m s}^{-2}$)

$v_0 = 0$, $g = -10\ \text{m s}^{-2}$, $h = -20$ m

'g' must be given a negative sign which means that acceleration due to gravity is always be downward.

Since the direction of displacement is downward, height is negative.



$$v^2 = v_0^2 + 2\,g\,h$$

$$= 0 + 2 \times (-10) \times (-20)$$

$$= 400$$

$$v = \pm\ 20\ \text{m s}^{-1}$$

Since the stone is falling, the direction of velocity of ball is downward. $v = -20\ \text{m s}^{-1}$

The time taken for the stone to reach the ground = t

$$h = v_0 t + \frac{1}{2} g t^2$$

$$(-20) = 0 + \frac{1}{2} \times (-10)\, t^2$$

$$t = 2 \text{ s}$$

Example (6) A ball is thrown upwards with a velocity of 40 m s^{-1}. How long does the ball stay in the air? What height does the ball reach?

The initial velocity is positive because the stone is thrown vertically upward from starting point (ground).

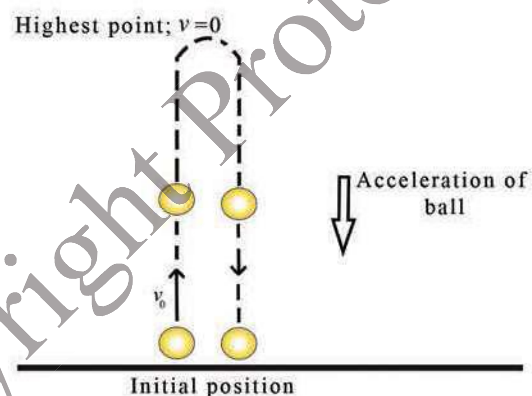
$v_0 = +\,40$ m s^{-1} (upward),

$g = -\,10$ m s^{-2}, $v = 0$ (at the highest point)

$v = v_0 + g\,t$

$0 = 40 + (-10)\,t$

$t = 4$ s



Since the time of ascending is the same as the time of descending, the total time the ball stays in the air $T = 2 \times 4 = 8$s

$$v^2 = v_0^2 + 2\,g\,h$$

$$0 = (40)^2 + 2 \times (-10) \times h$$

$$20\,h = 1600$$

$$h = 80 \text{ m}$$

Example (7) A ball is thrown vertically upward and it is caught again after 6 s.

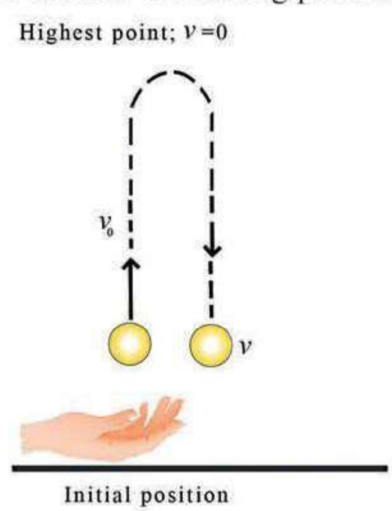
(a) Find the total displacement for the whole distance travelled.

(b) Find the velocity with which it is thrown.

(c) Find the maximum height reached.

(d) Find the average velocity for the whole distance travelled.

(a) Total displacement for the whole distance travelled is zero because the starting point and end point are the same.



(b) $v_0 = ?$, $t = 6$ s, $g = -\,10$ m s^{-2}, total displacement = 0

$$h = v_0 t + \frac{1}{2} g t^2$$

$$0 = v_0 \times 6 + \frac{1}{2}(-10)\, 6^2$$

$$v_0 = +\ 30 \text{ m s}^{-1} \text{ (upward direction)}$$

(c) Maximum height = ? , $v = 0$

$$v^2 = v_0^{\,2} + 2\,g\,h$$

$$0 = (30)^2 + 2\,(-10)\,h$$

$$h = +\,45 \text{ m}$$

(d) average velocity = ?

$$\text{average velocity} = \frac{\text{total displacement}}{\text{time taken}} = \frac{0}{6} = 0$$

Reviewed Exercise

- A stone is thrown vertically straight up with 40 m s^{-1}. What will be its respective velocities at 3 s , 4 s and 5 s after it have been thrown? Find the height of stone at 3 s, 4 s and 5 s.

Key Words : air resistance, freely falling

3.6 MOMENTUM AND LAW OF CONSERVATION OF MOMENTUM

According to the Newton's second law;

$$\vec{F} = m\vec{a} = m\left(\frac{\vec{v} - \vec{v}_0}{t}\right) \text{ (or) } \frac{m\vec{v} - m\vec{v}_0}{t}$$

where another important physical quantity in the above equation is the product of mass and velocity. Hence, momentum (p) of a body is defined as the product of the mass of the body and its velocity, which is written as

$$\vec{p} = m\vec{v} \qquad (3.11)$$

Momentum of a body is directly proportional to its velocity. Momentum is a vector quantity. Direction of momentum is the same as that of velocity. Unit of momentum is expressed as the product of mass unit and velocity unit. In MKS system it is kg m s^{-1}.

One fundamental law of physics is the law of conservation of momentum.
This law states that:

If there is no net external force acting on an isolated system, the total momentum of the system is constant.

The law of conservation of momentum is a general law and is true for both macroscopic and microscopic objects.
Let us consider a collision between two bodies of masses m_A and m_B. These two bodies constitute an isolated system shown in Figure 3.5 (a) and 3.5 (b).

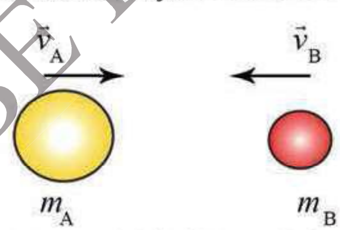


Figure 3.5 (a) before collision

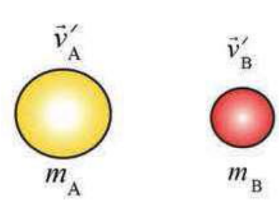


Figure 3.5(b) after collision

According to law of conservation of momentum,

Total momentum before collision = total momentum after collision

$$\vec{p}_A + \vec{p}_B = \vec{p}'_A + \vec{p}'_B$$

$$m_A\,\vec{v}_A + m_B\,\vec{v}_B = m_A\,\vec{v}'_A + m_B\,\vec{v}'_B$$

(d) average velocity = ?

$$\text{average velocity} = \frac{\text{total displacement}}{\text{time taken}} = \frac{0}{6} = 0$$

Reviewed Exercise

- A stone is thrown vertically straight up with 40 m s^{-1}. What will be its respective velocities at 3 s , 4 s and 5 s after it have been thrown? Find the height of stone at 3 s, 4 s and 5 s.

Key Words : air resistance, freely falling

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where another important physical quantity in the above equation is the product of mass and velocity. Hence, momentum (p) of a body is defined as the product of the mass of the body and its velocity, which is written as

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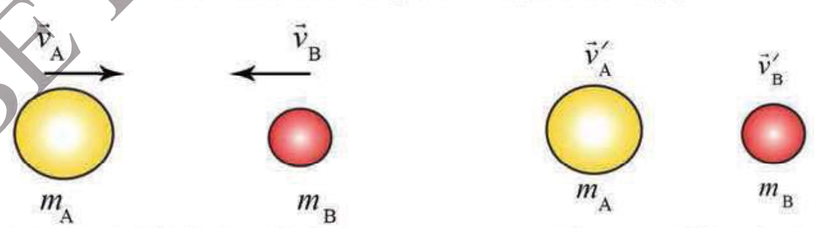

Figure 3.5 (a) before collision Figure 3.5(b) after collision

According to law of conservation of momentum,

Total momentum before collision = total momentum after collision

$$\vec{p}_A + \vec{p}_B = \vec{p}'_A + \vec{p}'_B$$

$$m_A\,\vec{v}_A + m_B\,\vec{v}_B = m_A\,\vec{v}'_A + m_B\,\vec{v}'_B$$

$\vec{v}_A$ and $\vec{v}_B$ are velocities of the masses before collision and $\vec{v}'_A$ and $\vec{v}'_B$ are their velocities after collision.

Let us apply the law of conservation of momentum to a very simple and easy case. A compressed spring is placed between two wooden balls of different sizes as shown in Figure 3.6. Both balls are initially at rest.

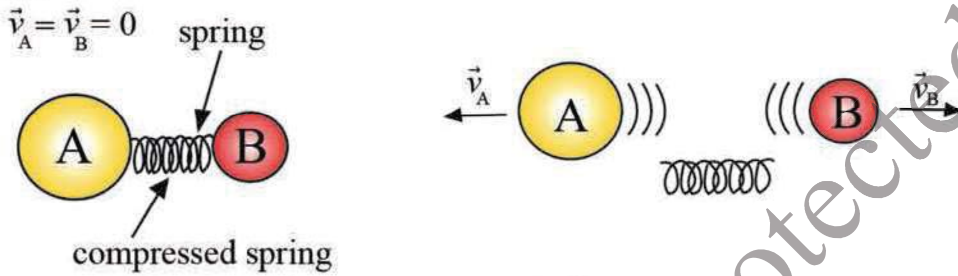

Figure 3.6 Change of momentum of two bodies due to compressed spring

When the spring is released, according to the conservation of momentum, total initial momentum is zero and so will be the final total momentum.

$$0 = m_A \vec{v}'_A + m_B \vec{v}'_B$$

$$m_B \vec{v}'_B = - m_A \vec{v}'_A$$

The minus sign indicates that the two velocity vectors are parallel but opposite in direction. Taking only the magnitude, we have; $m_B v'_B = m_A v'_A$

$$m_B = m_A \frac{v'_A}{v'_B} \qquad (3.12)$$

where v'_A and v'_B are the magnitude of the velocity vectors. By using this relation inertial mass can be measured.

Example (8) A bullet of mass 50 g leaves the muzzle of a gun with a velocity of 20 000 cm s^{-1}. Find the momentum of the bullet.

Since , $m = 50$ g and $v = 20\ 000$ cm s^{-1}, we have

$$p = mv = 50 \times 20\ 000$$
$$= 10^6 \text{ g cm s}^{-1}$$

Example (9) A bullet of mass 16 g (0.016 kg) is fired from a 4 kg gun with a velocity of 600 m s^{-1}. What is the recoil velocity of the gun?

$m_b = 0.016$ kg , $m_g = 4$ kg , $v_b = 600$ m s^{-1}

For a system consisting of a gun and a bullet , the total momentum before firing = 0

The momentum of the bullet after firing

$$p'_b = m'_b v'_b = 0.016 \times 600 = 9.6 \text{ kg m s}^{-1}$$

The momentum of the gun after firing,

$$p'_g = m'_g v'_g = 4 \times v'_g \text{ kg m s}^{-1}$$

By the law of conservation of momentum, we can write the total momentum before firing is equal to the total momentum after firing.

$$0 = 4\, v_g' + 9.6$$
$$v_g' = -\ 2.4 \text{ m s}^{-1}$$

The minus sign indicates that the direction of the recoil velocity of gun is opposite to that of velocity of the bullet.

Example (10) A soccer ball of mass 0.4 kg is moving towards south with 30 m s^{-1}. Goal keeper kicked it and moved north with 40 m s^{-1}. The contact time of kick is 0.4 s. Calculate the change in its momentum and force acting on it.

$$v_{\text{initial}} = 30 \text{ m s}^{-1} \text{ (north)}$$
$$v_{\text{final}} = 40 \text{ m s}^{-1} \text{ (south)}$$

The direction of velocity (north) is taken (+) sign.

Change in velocity $\Delta v = v_{\text{final}} - v_{\text{initial}}$

$$= 40 - (-\ 30)$$
$$= 70 \text{ m s}^{-1}$$

Change in momentum $\Delta p = m \times \Delta v = 0.4 \times 70 = 28 \text{ kg m s}^{-1}$

The direction of change in momentum is north.

$$a = \frac{v - v_0}{t} = \frac{\Delta v}{\text{t}} = \frac{28}{0.4}$$
$$= 70 \text{ m s}^{-2}$$

Force acting on the ball; $F = ma = 0.4 \times 70 = 28 \text{ N}$

The direction of force is also north.

Reviewed Exercise

1. How does the momentum of a body relate its velocity?
2. Rewrite the relation $m\dfrac{v - v_0}{t} \propto F$ in vector notation.

Key Words : isolated system, macroscopic, microscopic

SUMMARY

Mass is the quantity of matter in a body (or) a measure of inertia.
The attracting force of the earth acting on the body is defined as the **weight** of the body.
Momentum of a body is defined as the product of the mass of the body and its velocity.
Momentum is a vector quantity.
Gravitational force is force between two masses.

EXERCISES

1. Which is more difficult? To move a small stone (or) a big stone. Why?
2. A man weighing 600 N stands on the earth's surface. How much force does he exert on the earth? Explain.

By the law of conservation of momentum, we can write the total momentum before firing is equal to the total momentum after firing.

$$0 = 4\, v'_g + 9.6$$
$$v'_g = -\ 2.4 \text{ m s}^{-1}$$

The minus sign indicates that the direction of the recoil velocity of gun is opposite to that of velocity of the bullet.

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Change in momentum $\Delta p = m \times \Delta v = 0.4 \times 70 = 28$ kg m s^{-1}

The direction of change in momentum is north.

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Force acting on the ball; $F = ma = 0.4 \times 70 = 28$ N

The direction of force is also north.

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Mass is the quantity of matter in a body (or) a measure of inertia.
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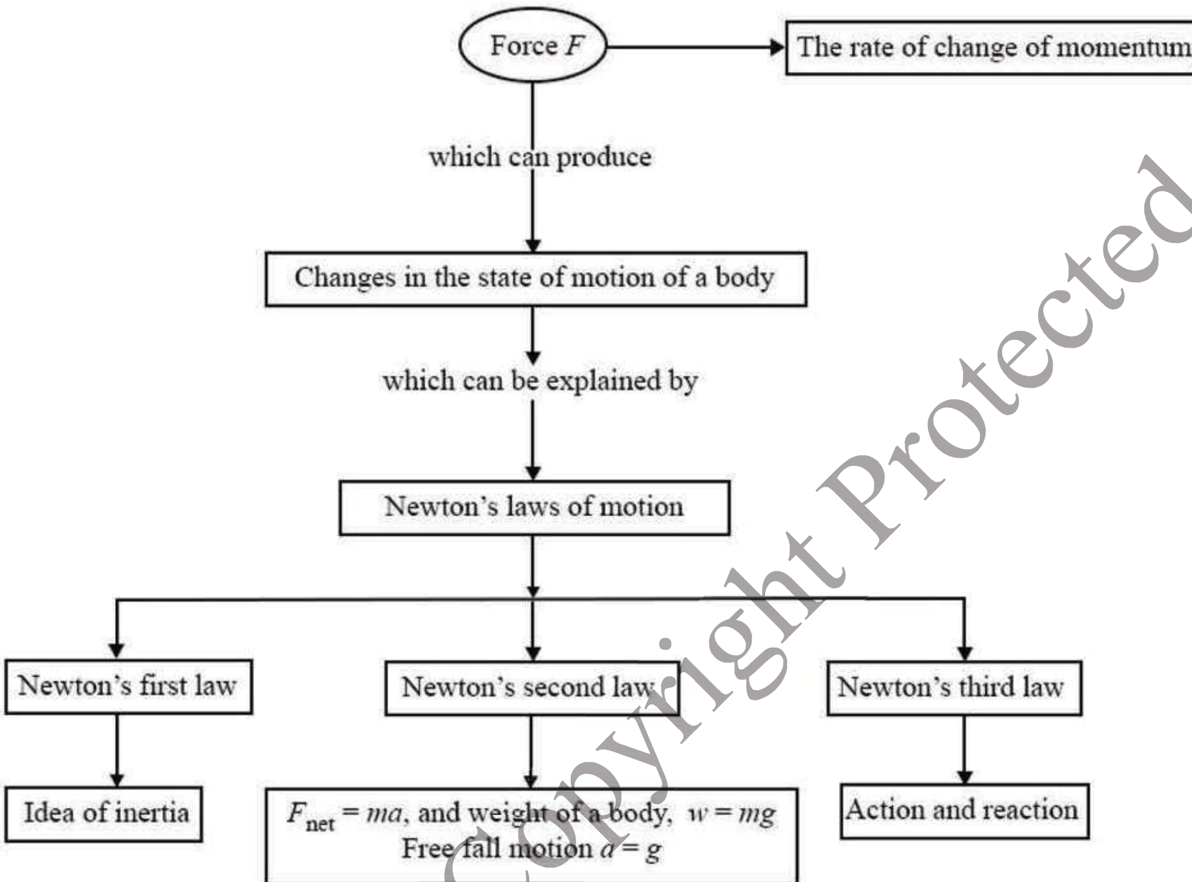
EXERCISES

1. Which is more difficult? To move a small stone (or) a big stone. Why?
2. A man weighing 600 N stands on the earth's surface. How much force does he exert on the earth? Explain.

3. If a proton of mass 1.675×10^{-24} g is accelerated by an accelerator to an acceleration of 10^{6} m s^{-2}, find the net force acting on the proton.
4. If the velocity of a car of 1 200 kg mass increases from 60 m s^{-1} to 120 m s^{-1} in 10 s, what is the net force acting on the car?
5. A truck of 2 000 kg mass moving at a velocity of 12 m s^{-1} slide 15 m before it comes to a stop after applying the brakes. Find the resisting force of the brakes.
6. What is the acceleration of a body weighing 20 N due to the applied force F_{net} = 20 N?
7. Compare the accelerations of the two bodies of masses M and 3M when the same net force of 20 N is applied to each of them.
8. A 3 ton car moving with the velocity of 30 mi h^{-1} is brought to a stop in 2 s. Find the resisting force of the brakes acting on the car.
9. A lift weighing 2 000 lb is pulled up by a cable of tension (force) 5 000 lb. Find the mass of the lift and its upward acceleration.
10. If a body weighing 100 N is carried to the moon and put on the moon's surface, what will happen to the weight of the body? Will the mass of the body change?
11. Compare the moon's gravitational forces acting on the two bodies of the masses M and 3M which are falling simultaneously onto the moon's surface from a height near the surface. If M = 0.2 kg and the acceleration due to the gravity of the moon is 1.6 m s^{-2}, find the moon's gravitational forces acting on each of the bodies.
12. The gravitational force of the moon is less than that of the earth. The moon's gravitational forces acting on a body of mass 1 kg is 1.6 N. What will be the weight of a 40 kg mass on the moon?
13. An object is hurled vertically upwards with a speed of 50 m s^{-1}. How long does it take the object to be caught again?
14. A man throws a stone vertically upward at 30 m s^{-1}. How long does it take the stone to reach the height of 40 m?
15. A stone, thrown by a girl, reaches a height of 20 m. How long does it take the stone to be caught back? With what velocity does she throw the stone?
16. If the velocity of a 0.02 kg bullet is 500 m s^{-1}, find the magnitude of the momentum of the bullet. If the bullet is fired towards the north, what is the direction of its momentum?
17. An object of mass 10 kg collides with a stationary object of mass 5 kg. If the objects stick together and move forward at a velocity of 4 m s^{-1}, what was the original velocity of the moving object?
18. A man dived horizontally with a velocity of 1.5 m s^{-1} from a 100 kg boat. If the recoil velocity of the boat is 0.9 m s^{-1}. What is the mass of the man?

CONCEPT MAP



Force F
The rate of change of momentum
which can produce
Changes in the state of motion of a body
which can be explained by
Newton's laws of motion
Newton's first law
Newton's second law
Newton's third law
Idea of inertia
$F_{net} = ma$, and weight of a body, $w = mg$
Free fall motion $a = g$
Action and reaction

CHAPTER 4

PRESSURE

Pressure, density and specific gravity are important quantities in physics and pressure is the basic of hydrostatic and hydrodynamic. The study of fluids at rest is called hydrostatics and the study of fluids at motion is hydrodynamic.

Learning Outcomes

It is expected that students will

- explain pressure and its units of daily usage.
- skillfully construct and use hydrometer to measure the density of liquids.
- distinguish between the density and the specific gravity.
- apply basic knowledge of pressure and density to daily-life phenomena.

4.1 PRESSURE

Pressure is defined as the force exerted normally on unit area.

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}} \qquad (4.1)$$

$$p = \frac{F}{A}$$

In SI units, pressure is measured in 'pascal' (Pa).

$$1 \text{ Pa} = 1 \text{ N m}^{-2}$$

The force in the pressure formula must be normal (90°) to the surface. Pressure is a scalar quantity.

From the definition of pressure, it is obtained that pointed nails penetrate the surfaces because for a definite force, the exerted area is too small.

Similarly sharp knives can cut easily than blunt knives because of smaller cutting area. Elephants have four large flat feet so they reduce the pressure and less likely sink into the ground.

Most obvious is tractors used for ploughing has large tire areas so that they do not sink in the muddy fields.

Pressure is applied in many scientific fields and many units are used although they have the same meaning.

In FPS system, the unit of pressure is pound per square inch (psi).

In Meteorology, the unit of pressure is hectopascal (hPa).

Standard Atmospheric Pressure is 1 atmosphere (1atm).
The relation between different units of pressure are ;

$1 \text{ atm} = 1.013 \times 10^5 \text{ Pa} = 760$ millimetre mercury (760 mm Hg)

$1 \text{ atm} = 1\,013 \text{ h Pa} = 1\,013$ millibar (1 013 mb)

$1 \text{ hPa} = 100 \text{ Pa} = 1 \text{ mb}$

$1\text{Pa} = 1.45 \times 10^{-4} \text{ lb in}^{-2}$ (psi)

$1\text{psi} = 6.90 \times 10^3 \text{ Pa}$

Example (1) Bicycle tire has 6 cm × 4 cm area touching the ground. The mass of the bicycle is 22 kg and mass of the cyclist is 60 kg. Find the minimum pressure needed in the tire.

Total area, $A = 2 \times (6\times4) = 48 \text{ cm}^2 = 48 \times 10^{-4} \text{ m}^2$

Total mass, $m = 60 + 22 = 82$ kg

$$F = w = mg = 82 \times 10 = 820 \text{ N}$$

$$p = \frac{F}{A} = \frac{820}{48\times10^{-4}} = 1.708 \times 10^5 \text{ Pa}$$

Example(2) Low pressure area in the bay of Bengal is 998 hPa. Fishing boat nearby has sail area 4 m^2 at the normal atmospheric pressure. (a) Find the pressure difference (b) Find the force exerted on the sail. (Hints : Force exerts due to the atmospheric pressure difference.)

$$\Delta p = p_{\text{atm}} - p_{\text{low pressure}} = 1\,013 \text{ hPa} - 998 \text{ hPa} = 15 \text{ hPa} = 1\,500 \text{ Pa}$$

$$F \text{ (Force exerted on the sail)} = \Delta p \times \text{sail area}$$

$$= 1\,500 \times 4 = 6\,000 \text{ N}$$

Example (3) The pressure in the motor car tire is 40 psi .What is the equivalent MKS unit and atm unit?

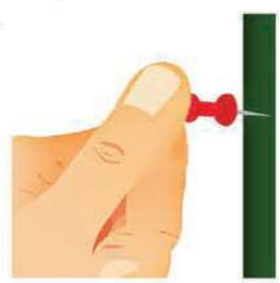
$1 \text{ psi} = 6.9 \times 10^3 \text{ Pa}$

$1 \text{ atm} = 1.013\times10^5 \text{ Pa}$

$40 \text{ psi} = 6.9 \times 10^3 \times 40 = 276\,000 \text{ Pa} = 276\,000 \text{ Nm}^{-2}$

$$40 \text{ psi} = 276\,000 \text{ Pa} = \frac{276\,000}{1.013 \times 10^5} = 2.724 \text{ atm}$$

Example (4) A drawing pin is pressed into the notice board. The pointed pin area is 0.25 mm^2 and the force exerted on the pin is 10 newton. Compute the pressure.



$A = 0.25 \text{ mm}^2 = 0.25 \times 10^{-6} \text{ m}^2$

$F = 10 \text{ N}$, $p = ?$

$$p = \frac{F}{A} = \frac{10}{0.25\times10^{-6}} = 4\times10^7 \text{Pa}$$

Reviewed Exercise

- A person exerts pressure on the floor when standing, sitting and lying. Explain why the pressure is different when the person is in each of these positions.

Key Words: pressure, normal force

4.2 DENSITY

There is Myanmar riddle 'Which is heavier, a viss of cotton (or) a viss of iron ?' (leading to the puzzle how small (or) large is the volume of them.)

Density is the ratio of mass to volume of a substance. Density is the scalar quantity.

$$\text{density} = \frac{\text{mass of substance}}{\text{volume of the substance}} \quad (4.2)$$

$$\rho = \frac{m}{V} \qquad [\rho = \text{rho} = \text{Greek alphabet}]$$

In SI unit, density is expressed in kilogram per cubic metre ($kg\ m^{-3}$).

In CGS unit, it is expressed in gram per cubic centimetre ($g\ cm^{-3}$) or gram per mililitre ($g\ mL^{-1}$).

Mass of an object can be measured using a balance and volume can be measured using a measuring cylinder. When studying three states of matter (solid, liquid and gas), density is an important factor. Mass of the object does not change, but the volume depends on the temperature. If the volume changes, the density will change. Densities of some substances are shown in Table 4.1.

Table 4.1 Densities of some substances

Substances	CGS ($g\,cm^{-3}$)	MKS ($kg\,m^{-3}$)
helium	1.64×10^{-4}	0.164
air	1.3×10^{-3}	1.3
water, $4^{\circ}C$	1	1 000
ice, $0^{\circ}C$	1.029	1 029
aluminium	2.7	2 700
copper	8.9	8 900
lead	11.4	11 400
mercury	13.6	13 600
gold	19.3	19 300
uranium	19.05	19 050

(**Note** Average density of a human body is a little less than water density)

Example (5)

The helium flying balloon has the size of 6 m radius.
(a) Find the volume and mass of helium.
(b) Find the mass of air displaced by the balloon.
(Assume, $\rho_{\text{helium}} = 0.164\,\text{kg m}^{-3}$, $\rho_{\text{air}} = 1.3\,\text{kg m}^{-3}$)

(Hint: volume $= \frac{4}{3}\pi r^3$, mass = density × volume)

$r = 6$ m

(a) $V = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi \times 6^3 = 904.8\ \text{m}^3$

mass of helium = $\rho_{\text{Helium}} \times$ volume
$= 0.164 \times 904.8 = 148.4$ kg

(b) $m_{\text{air}} = \rho_{\text{air}} \times$ volume $= 1.3 \times 904.8 = 1\,176$ kg

Example (6) A concrete slab 1.0 m by a 0.5 m by 0.1 m has a mass of 120 kg. What is the density of the concrete?

$m = 120$ kg , $\rho = ?$

Volume = length × width × height
= 1.0 × 0.5 × 0.1
= 0.05 m^3

$$\rho = \frac{m}{V}$$

$$= \frac{120}{0.05} = 2\,400\ \text{kg m}^{-3}$$

Reviewed Exercise

- We say that the density of iron is 7.9 g cm^{-3}. Write this in kg m^{-3}.

Key Words : mass, volume, density

4.3 RELATIVE DENSITY (OR) SPECIFIC GRAVITY

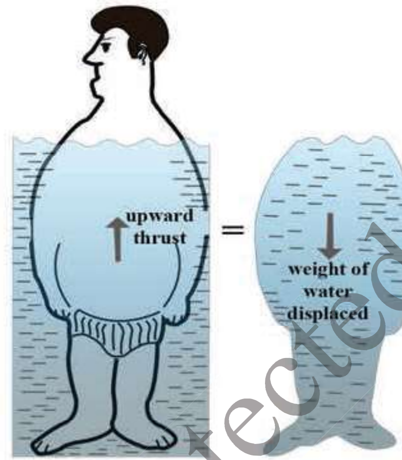
Relative density is how much a substance is denser than water. Relative density is also known as specific gravity.

$$\text{relative density} = \frac{\text{density of substance}}{\text{density of water at } 4\,^{\circ}\text{C}} \qquad (4.3)$$

As the density of water is 1 g cm^{-3} in CGS units, then density of substance can be taken as the relative density.

For example, the density of aluminium is 2.7 g cm^{-3} and so relative density of aluminium is 2.7. As the relative density is the ratio of two densities, it is just a number without unit.

"Archimedes' Principle" (250 B.C)



Part I - When an object is partially (or) totally immersed in a liquid, the object displaces liquid volume that is equal to the volume of the immersed portion.

Part II - The loss in weight of the object is equal to the weight of the liquid displaced. (or) The upward thrust acting on a body which is immersed partially or totally in a liquid is equal to the weight of the liquid displaced by the body.

This is the introduction of Archimedes' principle.

upward thrust = uplift force = buoyancy = weight of liquid displaced

> By Archimedes' principle, weight of a body is more than buoyancy (or) upward thrust, it will sink in the liquid. Substances having relative density greater than one will sink in water.

Archimedes and the Crown

King of Syracuse was suspicious with his crown; King let Archimedes to test whether the crown was made of pure gold. The crown had mass 3.75 kg or 3 750 g. As the density of gold is 19.3 g cm^{-3}, the crown must have volume 194 cm^3. Archimedes found that the volume(by his principle Part I) was 315 cm^3. Then, he answered to the King that the crown was not pure gold. (Hint-The added metal is copper because it has similar color.)

The mass of gold in the crown is M_g and mass of copper be M_{Cu},
M_g can be calculated by solving these simultaneous equations.

$$\frac{M_g}{19.3} + \frac{M_{Cu}}{8.9} = 315 \quad \text{and} \quad M_g + M_{Cu} = 3\ 750$$

(The student can extended the problem why the gold smith did not use lead metal instead of copper.)

Reviewed Exercise

- The relative density of sulphur is 2. Find the volume of 1 kg of sulphur.
  (density of water = 1 000 kg m^{-3})

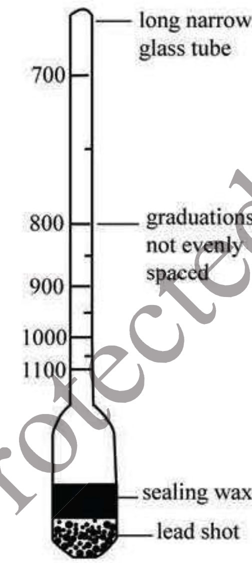
Key Words: relative density

4.4 HYDROMETER

When an object is placed in a liquid of a lower density, the object sinks. If it is placed in a liquid of a greater density, it floats.

Since the amount of submerged portion for a floating body is inversely propotional to the specific gravity of the liquid the more submerged, the less the specific gravity.

The hydrometer is an instrument for measuring the density (or) relative density of liquids. It usually consists of a glass tube with a long bulb at one end. The bulb is weighted with lead shot so that the device floats vertically in the liquid, as shown in figure, the relative density being read off its calibrated stem by the depth of immersion. If the hydrometer floats higher, it indicates that the liquid has a higher density.

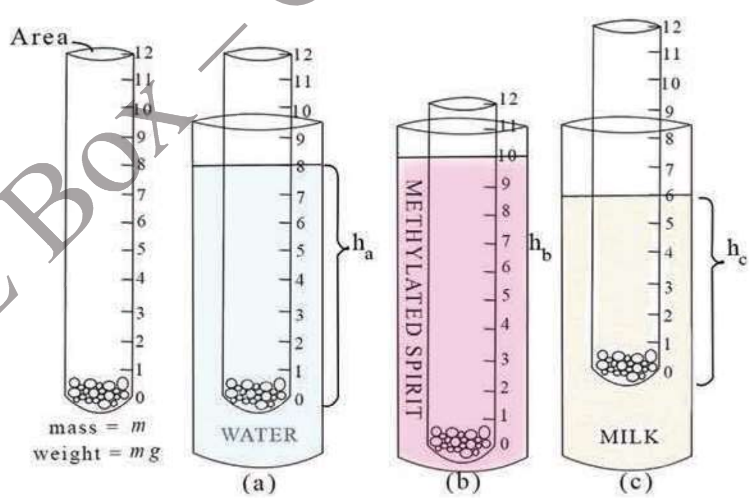


The hydrometer sinks in the liquid until the weight of the liquid displaced is equal to the weight of the hydrometer. The hydrometer is calibrated to measure the density of the liquid in kg m^{-3}.

Special hydrometers are used to test the specific gravity of solutions in storage batteries in order to determine the condition of the battery. The relative density of the acid in a fully charged car battery is 1.25. Milk and wine can be tested to make sure they have not been diluted with water.

Test tube as a hydrometer

Hydrometer is a test tube like cylinder with overall density less than one (or) less than the density of water. So, hydrometer needs to float vertically in liquid.



The mass of hydrometer $= m$

The weight of hydrometer $= mg$

The hydrometer is floating in water (Fig - a)

Weight of hydrometer = Weight of water displaced

= (volume of water displaced × density of water)×g

$$mg = A\,h_a \rho_{\text{water}}\, g$$

The hydrometer is floating in methylated spirit (Fig - b)

$$mg = A\,h_b \rho_{\text{spirit}}\, g$$

The hydrometer is floating in milk (Fig - c)

$$mg = A\,h_c \rho_{\text{milk}}\, g$$

For specific gravity of methylated spirit,

$$A\,h_a \rho_{\text{water}}\, g = A\,h_b \rho_{\text{spirit}}\, g$$

$$\frac{\rho_{\text{spirit}}}{\rho_{\text{water}}} = \frac{h_a}{h_b}$$

$$= \frac{8}{10} = 0.8$$

For specific gravity of milk,

$$A\,h_a \rho_{\text{water}}\, g = A\,h_c \rho_{\text{milk}}\, g$$

$$\frac{\rho_{\text{milk}}}{\rho_{\text{water}}} = \frac{h_a}{h_c}$$

$$= \frac{8}{6} = 1.33$$

Reviewed Exercise

- An alloy is made by mixing 360 g of copper, of density 9 g cm^{-3}, with 80 g of iron, of density 8 g cm^{-3}. Find the density of the alloy. Assuming the volume of each metal used does not change during mixing.

Key Words : hydrometer, upward thrust, liquid displaced

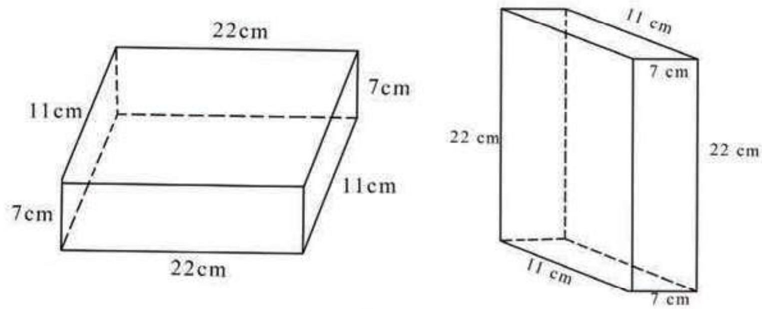
SUMMARY

Pressure is force acting on unit area; pressure is scalar quantity.
Density is the ratio of mass to volume of a substance.
Relative density is the ratio of density of substance to density of water; it has no unit.
Hydrometer is an instrument for measuring the density (or) relative density of liquids.

EXERCISES

1. Normal atmospheric pressure 1 atm is equal to 1.013×10^5 Pa. How much force due to atmosphere acts on a man whose total area is 2 m^2 ?
2. A man has mass 55 kg. His foot has the dimension of 24 cm × 8 cm. Find the pressure on his feet.
3. A four wheels truck has each tire 20 cm × 12 cm area touching the ground. The mass of the truck and the passengers are altogether 4 400 kg. Find the minimum pressure needed in a tire.

4. A brick of mass 2 kg has length 22 cm, breadth 11 cm and height 7 cm.
   Calculate the weight and 3 kinds of pressure when it lies on a plane for three positions. In the missing (c), draw a sketch with base 22 cm × 7 cm.

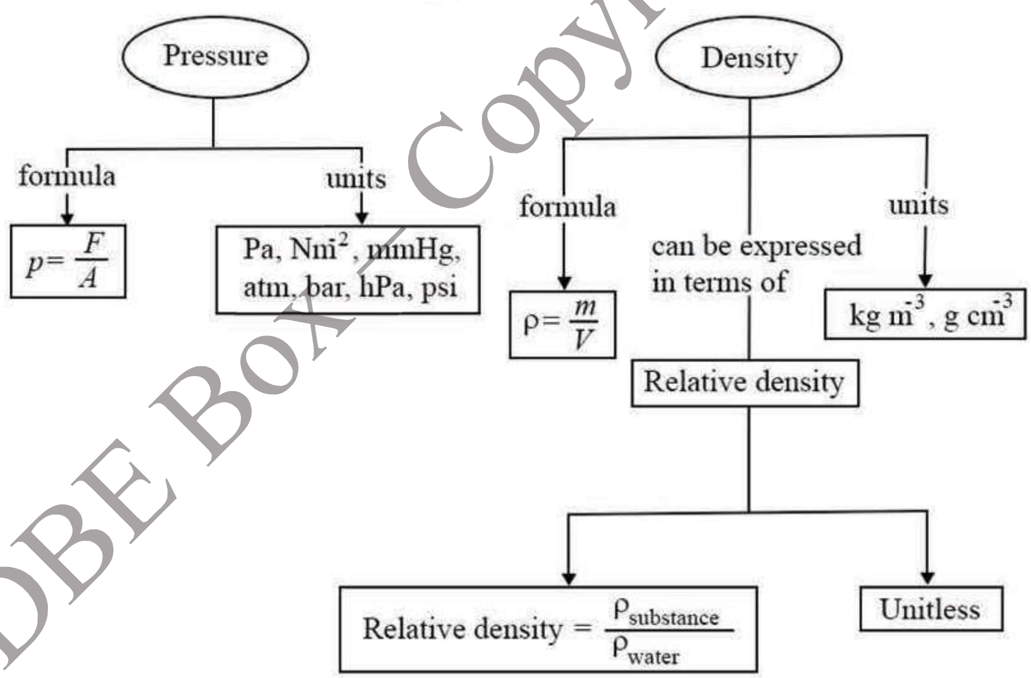


(a) (b) (c)

5. One litre of milk (density 1.2 g cm^{-3}) is mixed with 0.5 litre of water (density 1 gcm^{-3}). What is the density of the mixture? Find the relative density of the mixture.

6. Mini-submarine has the total volume of 24 m^3. Its mass is 2 000 kg. Can it carry a load of another 3 000 kg?

CONCEPT MAP



CHAPTER 5
WORK AND ENERGY

In this chapter work and mechanical energy will be discussed. Before discussing mechanical energy it is necessary to introduce a concept called 'work' which is related to energy.

Learning Outcomes

It is expected that students will

- develop an understanding of work as a physics student compared to an ordinary person.
- evaluate the mathematical expressions of work done.
- investigate gravitational potential energy and the elastic potential energy.
- realize the relationship between work and energy.
- demonstrate that energy can be transformed from one form to another and how it is conserved.
- apply basic knowledge of work and energy to daily-life phenomena.
- use mathematical relationships of work and energy in solving problems.

5.1 WORK

Normally, the work is used to describe the different kinds of activities that people do every day. In physics, work specifies the action (force) and the movement produced by the force.

Work is said to be done when a force produces motion.

Work is defined as the product of force and distance moved in the direction of the force.

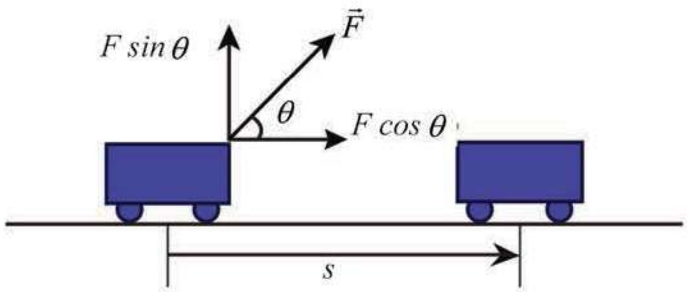
$$W = F\,s \tag{5.1}$$

where 'W' is work done, 'F' is force acting on the particle and 's' is the distance moved in the direction of the force.

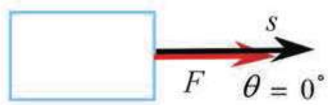
Work is a scalar quantity. The SI unit of work is the joule (J). 1 joule of work is done when a force of 1 newton moves an object through a distance of 1 metre in the direction of the force. When the unit of force is in pound (lb) and the distance is in foot (ft), the unit of work is foot-pound (ft-lb). When the unit of force is in dyne and the distance is in centimetre, the unit of work is erg. (1 J = 10^7 ergs)

When the force is constant, and the direction of the force makes an angle θ with that of motion, work is defined as follows.

$$W = (F\cos\theta)s = Fs\cos\theta \tag{5.2}$$

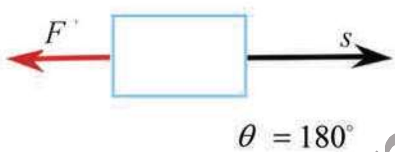


(i) when the directions of the force and the motion are the same



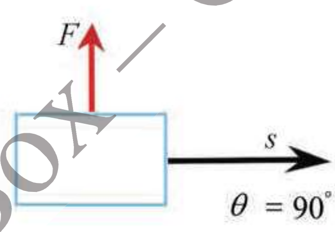
$$W = F\,s\cos\theta$$
$$\cos\theta = \cos 0^\circ = 1$$
$$W = F\,s$$

(ii) when the force and the motion are in opposite directions



$$W = Fs\cos\theta$$
$$\cos\theta = \cos 180^\circ = -1$$
$$W = -F\,s$$

(iii) when the force and the motion are perpendicular to each other



$$W = F\,s\cos\theta$$
$$\cos\theta = \cos 90^\circ = 0$$
$$W = 0$$

Figure 5.1 Examples of work done by constant forces

Example (1) A child is pulling a toy car with a 10 N force.The direction of the force makes an angle of 20° with horizontal plane. If the car moves 6 m, how much work does the child do?

$$F = 10\text{ N}, \theta = 20^\circ, s = 6\text{m}$$
$$W = F\,s\cos\theta$$
$$= 10\times 6\times\cos 20^\circ = 56.38\text{ J}$$

Example (2) How much work is done when a box is pushed with a force of 20 N through horizontal distance of 3 m?

$$F = 20\text{ N},\ s = 3\text{ m}$$

Since, F and s are in the same direction, $\theta = 0^\circ$

$$W = F\, s \cos\theta$$
$$= 20 \times 3 \times \cos 0^\circ$$
$$= 60\text{ J}$$

Reviewed Exercise

- A woman pushes a child, who is riding a tricycle, with a 200 N force. The tricycle moves a distance of 2 m and the work done by the woman is 100 J. Find the angle between the force and the displacement.

Key Words: force, work

5.2 ENERGY

Energy is defined as the capacity to do work.

The SI unit for energy is joule (J). Energy is a scalar quantity. Energy possessed by a body is measured by the amount of work done. Whenever work is done on the body, the energy gained by the body is equal to the amount of work done. There are different forms of energy. They are mechanical energy, heat energy, light energy, electrical energy, nuclear energy and so on. In this chapter only mechanical energy will be discussed.

Mechanical Energy

The mechanical energy is divided into two types : kinetic energy and potential energy.

Kinetic Energy (KE)

Energy acquired by a body due to its motion is called kinetic energy.

Let us consider a body of mass m which is at rest. Let an external force F_{external} be applied to the body. Then, according to Newton's second law, the acceleration of the body must be

$$a = \frac{F_{external}}{m}$$

Due to the applied force the body will be in motion and its velocity increases to v after travelling the distance s, we have

$$v^2 = 2as$$

$$v^2 = 2\left(\frac{F_{external}}{m}\right)s$$

$$\frac{1}{2}mv^2 = F_{external}\, s$$

In the above equation, $F_{\text{external}}\ s$ is the work done on the body and is the amount of energy given to the body. Therefore, $\frac{1}{2}mv^2$ is the kinetic energy received by the body which is expressed as

$$KE = \frac{1}{2}mv^2 \qquad (5.3)$$

If the body is moving with an initial velocity v_0 and its final velocity is v then the change in kinetic energy is

$$\Delta KE = \frac{1}{2}mv^2 - \frac{1}{2}mv_0^2 = F_{external}s \qquad (5.4)$$

The change in kinetic energy is equal to the work done.

Example (3) A truck with mass 1 500 kg is travelling with speed of 20 m s^{-1}. What is the kinetic energy of the truck?

$$m = 1\ 500 \text{ kg},\ v = 20 \text{ m s}^{-1}$$

$$KE = \frac{1}{2}mv^2$$

$$KE = \frac{1}{2} \times 1\ 500 \times 20^2$$

$$KE = 300\ 000 = 3 \times 10^5 \text{ J}$$

Potential Energy (*PE*)

The energy stored in a body due to its position or configuration is called the potential energy.

Gravitational Potential Energy

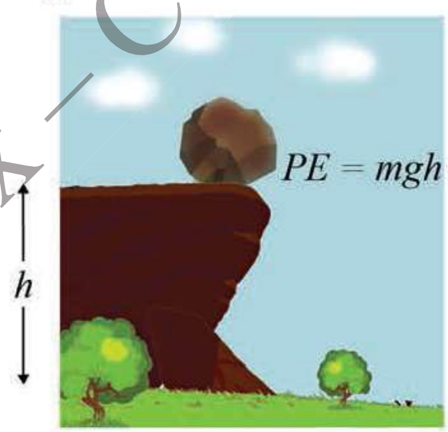


Figure 5.2 A rock on the top of a cliff has the gravitational potential energy

Let us consider a body of mass m which is on the ground. When the body is raised to a height h above the ground, the amount of work done against the gravitational force mg is

$$W = Fs = mgh.$$

This amount of work done (mgh) is stored by the body as gravitational potential energy. Thus the energy stored in a body due to its position is called the gravitational potential energy (PE).

$$PE = mgh \qquad (5.5)$$

Gravitational potential energy is the energy which a body possesses because of its position relative to the ground.

When an object with mass m near the Earth's surface is raised from a height h_0 to a height h, the change in potential energy is given by

$$\Delta PE = mgh - mgh_0 \tag{5.6}$$

where, g = acceleration due to gravity

The change in potential energy is equal to the work done.

Elastic Potential Energy

The potential energy due to configuration is called elastic potential energy. For examples, the energy stored in the compressed or stretched springs, the stretched rubber band of a catapult (or) the stretched bow.

The elastic potential energy in compressed (or) stretched springs $= \frac{1}{2} k x^2$

where k = spring constant, x = extension (or) compression of spring.

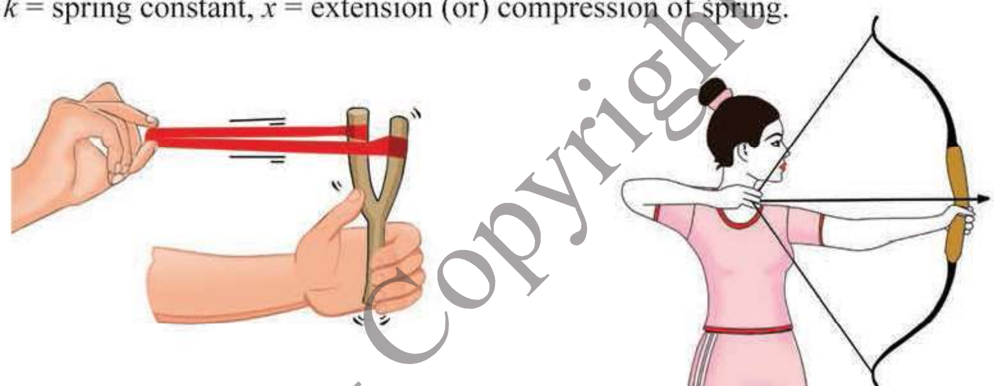


Figure 5.3 Elastic potential energy due to a stretched elastic rubber band and a stretched bow

Example (4) A girl lifts her school bag of mass 3 kg from the floor onto her lap through a height of 0.5 m. What is the gravitational potential energy gained by the bag?

$$m = 3\text{ kg}, \; h = 0.5\text{ m}$$

Gravitational potential energy gained

$$PE = mgh = 3 \times 10 \times 0.5 = 15\text{ J}$$

Example (5) How much more gravitational potential energy does a 20 kg box have when it is moved from a shelf 0.3 m height to a shelf 1.8 m height?

$$m = 20\text{ kg}, \; h = 1.8\text{ m}, \; h_0 = 0.3\text{ m}$$

Gravitational potential energy gained $(\Delta PE) = mgh - mgh_0 = mg(h - h_0)$

$$= 20 \times 10 \times (1.8 - 0.3)$$
$$= 20 \times 10 \times 1.5 = 300\text{ J}$$

Conservation of Energy

The law of conservation of energy is a very important rule. It states that:
The total energy of an isolated system is constant.

This law is also expressed as:
Energy cannot be created (or) destroyed in any process. The total energy of the universe is constant. These two statements are equivalent. In the second statement the whole universe is taken as an isolated system.

Energy cannot be created (or) destroyed but energy can be changed from one form to another. Therefore, for an isolated system the sum of the different forms of energy must be constant.

Physicists believe that the amount of energy in the universe is constant. Energy can be changed from one form to another but there is never any more (or) any less of it.

Let us verify the conservation of energy with a particular example.

Let us consider a two-particle system which consists of only a stone and the earth. Let the mass of the stone be m. The stone is dropped from a height h_0 above the ground. The freely falling stone and the earth are attracting each other with equal forces. But only the motion of the stone is noticeable and the motion of the earth can be neglected since the mass of the earth when compared with the stone is many times larger.

Due to the gravitational force acting on the stone its acceleration will be g. Let us assume that the stone has fallen from the height h_0 to the height h and its velocity changes from v_0 to v during the period of time t. The kinetic energy will change because the velocity of the stone changes. The relationship between the energy change and work is

$$W = \frac{1}{2}mv^2 - \frac{1}{2}mv_0^2$$

$$W = F\,s$$

Since the weight of the stone $F = m\,g$ and the distance s = $h_0 - h$, we get

$$mg\,(h_0 - h) = \frac{1}{2}\,mv^2 - \frac{1}{2}\,mv_0^2$$

$$\frac{1}{2}mv^2 + mgh = \frac{1}{2}mv_0^2 + mgh_0$$

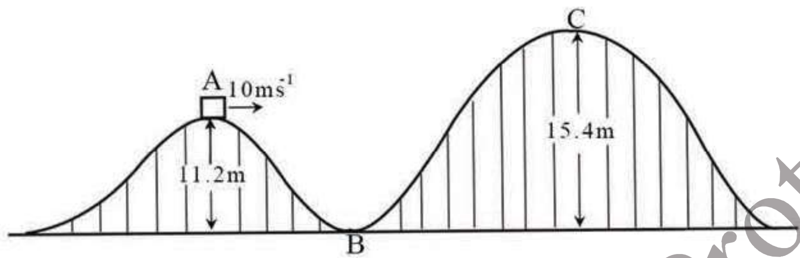
The quantity at the left is the sum of the potential energy and the kinetic energy or the total mechanical energy at the time t after the stone has started to fall; and the quantity at the right is the initial total mechanical energy of the stone. The value of this quantity (the total mechanical energy) is conserved throughout the distance travelled by the falling stone. It can be easily remembered by writing it as

kinetic energy + potential energy = total energy = constant

If the symbol KE is used for kinetic energy, PE for potential energy and E for total energy the above relation can be represented as

$$E = KE + PE = \text{constant}$$

Example (6) The figure shows the heights above the ground of some points on the track of a roller coaster. The speed of the carriage at A is 10 m s^{-1}. What is the speed of the carriage at B and C? The friction and air resistance are assumed to be negligible.



The total energy at B = Total energy at A

$$\frac{1}{2}mv_B^2 = mgh_A + \frac{1}{2}mv_A^2 \quad (PE \text{ at B} = 0)$$

$$\frac{1}{2}mv_B^2 = (m\times10\times11.2) + \frac{1}{2}\times m\times(10)^2$$

$$v_B^2 = 2(112+50)$$

$$= 324$$

$$v_B = 18 \text{ m s}^{-1}$$

The total energy at C = Total energy at A

$$mgh_C + \frac{1}{2}mv_C^2 = mgh_A + \frac{1}{2}mv_A^2$$

$$(m\times10\times15.4) + \frac{1}{2}\times m\times v_C^2 = (m\times10\times11.2) + \frac{1}{2}\times m\times(10)^2$$

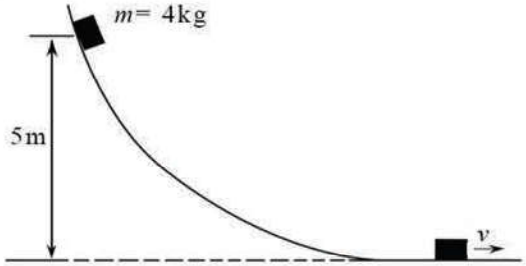
$$154 + \frac{1}{2}v_C^2 = 112 + \frac{1}{2}\times(10)^2$$

$$v_C^2 = 2\times[112 + \frac{1}{2}\times(10)^2 - 154]$$

$$v_C^2 = 16$$

$$v_C = 4 \text{ m s}^{-1}$$

Example (7) A parcel of mass 4 kg slides down a smooth curved ramp as shown in figure. What is the speed of the parcel when it reaches the bottom?



At the top of the ramp, the parcel has only gravitational potential energy. As the parcel slides down the ramp, it gradually loses its potential energy and gains kinetic energy. By the time it reaches the bottom, all the potential energy has been changed to kinetic energy.

Total energy at the bottom of the ramp = Total energy at the top of the ramp

$$\frac{1}{2}mv^2 = mgh$$

$$\frac{1}{2}\times 4\times v^2 = 4\times 10\times 5$$

$$v^2 = 2\times 10\times 5 = 100$$

$$v = 10\ \text{ms}^{-1}$$

Reviewed Exercise

1. Give the examples of electrical energy transforming into light energy.
2. Why are the units of energy and work the same?
3. Write down the law of conservation of energy. Identify this law as being a fundamental law or not and explain your answer.

Key Words: energy, kinetic energy, potential energy, gravational potential energy, elastic potential energy, conservation of energy

SUMMARY

Work is defined as the product of force and distance moved in the direction of the force.

Energy is defined as the capacity to do work.

Energy acquired by a body due to its motion is called **kinetic energy**.

The energy stored in a body due to its position or configuration is called the **potential energy**.

Gravitational potential energy is the energy which a body possesses because of its position relative to the ground.

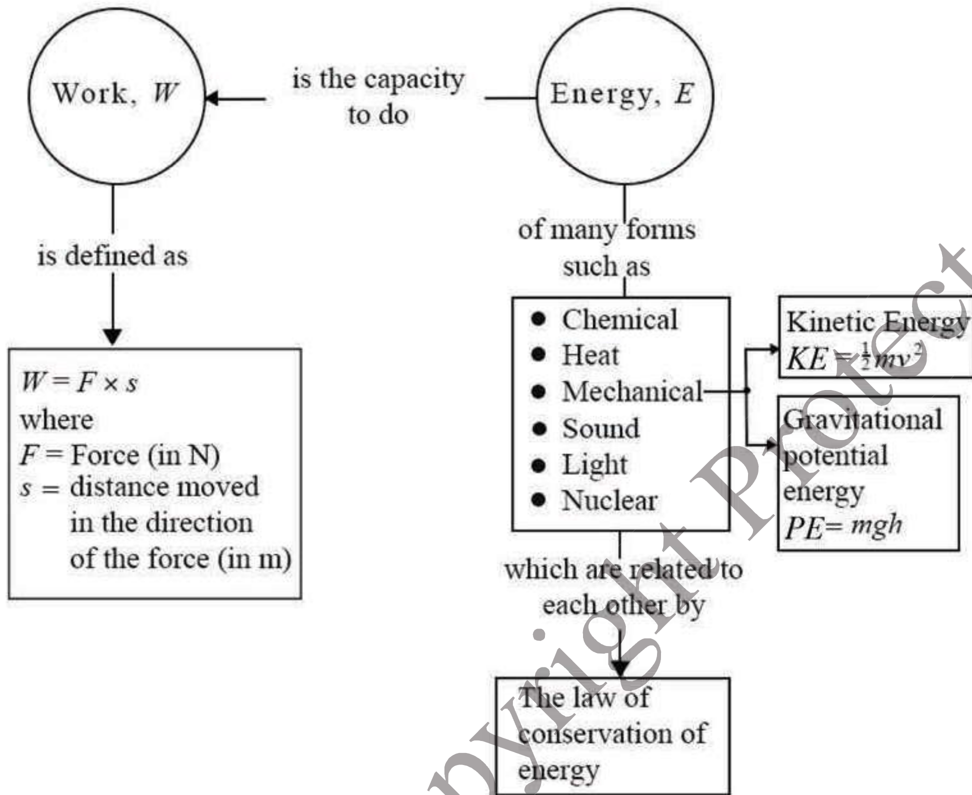
The potential energy due to configuration is called **elastic potential energy**.

The law of conservation of energy states that: the total energy of an isolated system is constant.

EXERCISES

1. A car with a mass of 800 kg travels at a speed of 20 m s^{-1}.What is its kinetic energy?
2. What is the change in potential energy of a flower pot of mass 2 kg that falls from a balcony? The height of the balcony from the ground is 20 m. What happens to this energy?
3. What is the change in potential energy if you move a brick of 1.5 kg mass through a distance of 0.4 m on a horizontal table?
4. A ball is thrown vertically upwards with a velocity of 10 m s^{-1}. What is the maximum height it can reach?
5. Calculate the kinetic energy of
   (a) 1 kg mass of a toy car moving at 2 m s^{-1},
   (b) 2 g (0.002 kg) bullet travelling at 400 m s^{-1},
   (c) 500 kg car travelling at 72 km h^{-1}.
6. (a) What is the velocity of an object of mass 1 kg which has 200 J of kinetic energy?
   (b) Calculate the potential energy of a 5 kg mass when it is (i) 3 m, (ii) 6 m, above the ground. ($g = 10$ N kg^{-1})
7. A 100 g steel ball falls from a height of 1.8 m onto a metal plate and **rebounds** to a height of 1.25 m. Find
   (a) potential energy of the ball before the fall ($g = 10$ m s^{-2}),
   (b) its kinetic energy as it hits the plate,
   (c) its velocity on hitting the plate,
   (d) the kinetic energy as it leaves the plate on the rebound,
   (e) its velocity of rebound.
8. The block of wood is placed on a rough horizontal plane. If the friction between the block and the plane is 6 N, what is the work done to move the block through a distance of 1.5 m?
9. A student lifts a box weighing 50 N through a vertical height 1.1 m and then walks horizontally for 2.0 m at constant speed while holding the box. What is the work done by the student on the box?
10. A weightlifter raising an object that weight is 500 N through a distance of 2 m. How much work is done?
11. A man lifts a brick of mass 5 kg from the floor to a shelf 3 meters high. How much work is done?
12. A tennis ball which is thrown verticaly upward reaches the height of 50 m. Find the initial velocity of the ball. (Neglect air resistance)

CONCEPT MAP


Work, W
is the capacity to do
Energy, E
is defined as
$W = F \times s$
where
F = Force (in N)
s = distance moved in the direction of the force (in m)
of many forms such as
Chemical
Heat
Mechanical
Sound
Light
Nuclear
Kinetic Energy
$KE = \frac{1}{2}mv^2$
Gravitational potential energy
$PE = mgh$
which are related to each other by
The law of conservation of energy

CHAPTER 6

HEAT AND TEMPERATURE

The concept of temperature is very important for the physical and biological sciences. This is because the temperature of an object is directly related to the energies of molecules composing the object. Natural processes often involve energy changes and the temperature is an indicator for these changes.

Learning Outcomes

It is expected that students will

- identify that thermal energy is an internal energy of a matter.
- explain why heat is considered to be a form of energy.
- distinguish between heat and temperature.
- examine thermometric properties of substances and differentiate thermometric properties of mercury and alcohol.
- examine linear, area and volume expansion.
- explain heat as the energy transferred between substances that are at different temperatures.
- apply basic knowledge and skill of thermal physics to daily-life phenomenon such as thermal expansion.

6.1 HEAT AND TEMPERATURE

The sensations of hotness, warmness and coldness can be experienced by touching objects. Temperature is the quantity that determines how cold (or) how hot the object is. The temperature of a hot body is higher than that of a cold body. To measure temperature accurately, we use instruments called thermometers.

There is a relation between heat and temperature. The energy exchanged between an object and its surrounding due to different temperatures is defined as heat. Heat is the energy in transit. The unit of heat is the same as units of energy. Heat and temperature are different quantities. When a body at a higher temperature is in contact with a body at a lower temperature, heat flows from the first to the second body.

The motions and positions of molecules in matter result in the kinetic energy and potential energy. The total energy, that is, the sum of the potential energy and the kinetic energy, of molecules in matter is in fact the internal energy of that matter. Temperature is related to that internal energy. Temperature is a measure of the internal energy of molecules.

Key Words: internal energy, energy exchange

Reviewed Exercise

- Distinguish between heat and temperature.

6.2 TYPES OF THERMOMETER

Every thermometer uses a physical property that varies with temperature. This property is referred to as the thermometric property of the thermometer. For example, the thermometric property of a liquid-in-glass thermometer is the thermal expansion of the liquid.

Liquid-in-Glass Thermometer

The liquid-in-glass thermometer consists of a thin glass bulb joined to a capillary tube with a narrow bore which is sealed at its other end. The liquid fills the bulb and the adjoining section of the capillary tube **(Figure 6.1)**. When the bulb becomes warmer:

- the liquid in it expands more than the bulb so some of the liquid in the bulb is forced into the capillary tube.
- the thread of liquid in the capillary tube increases in length.
- the thinner the bulb wall is, the faster the response of the thermometer will be when the temperature changes.

The liquid used usually contains mercury (or) coloured alcohol. Alcohol has a lower freezing points than mercury so it is more suitable for low-temperature measurements.

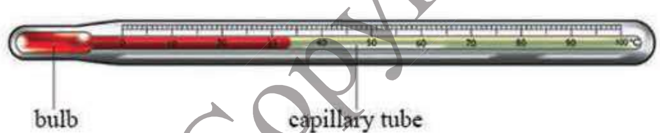


Figure 6.1 A liquid-in-glass thermometer

Thermocouple Thermometer

Thermocouple thermometers are electrical thermometers which make use of the voltage that develops when two different metals are in contact. This voltage varies with temperature. An iron wire and two copper wires may be used to make a thermocouple thermometer, as shown in Figure 6.2. One of the junctions is maintained at 0 ˚C and the other junction is used as the temperature probe. The voltmeter can be calibrated directly in ˚C.

Because of the small size of a thermocouple junction, thermocouple thermometers are used to measure rapidly changing temperatures. In addition, they can be used to measure much higher temperatures than liquid-in-glass thermometers. Also, the voltage of a thermocouple can be measured and recorded automatically.

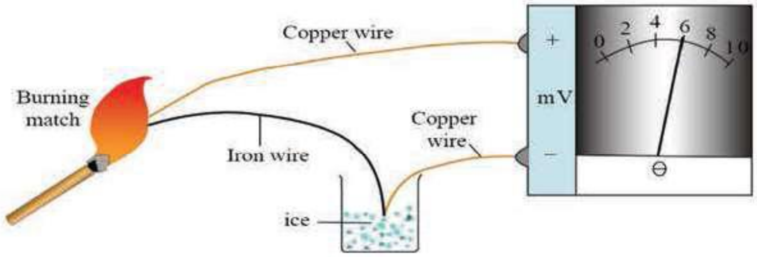


Figure 6.2 A thermocouple thermometer

Resistance Thermometer

Resistance thermometer uses the fact that the electrical resistance of a metal (e.g platinum) wire increases with temperature.

A resistance thermometer can measure temperatures accurately in the range −200 °C to 1 200 °C and best for steady temperatures, but it is bulky.

Thermometric substances can be solids, liquids (or) gases. They have physical properties that vary continuously and linearly with temperature. These properties are called thermometric properties.

Reviewed Exercise

1. State the physical property that varies with temperature in
   (a) liquid-in-glass thermometer, (b) thermocouple thermometer.
2. Why the temperature range of a clinical thermometer is from 35 °C to 42 °C?

Key Words: thermometric properties, temperature difference, voltage, electrical resistance

6.3 UNITS OF TEMPERATURE (OR) TEMPERATURE SCALES

Temperature units depend on the scale used. The temperature scales most widely used today are Celsius (Centigrade), Fahrenheit and Kelvin scales. The SI unit of temperature is kelvin (K).

To calibrate a thermometer, two reference points are chosen and the interval between these points is subdivided into a number of equal parts. The freezing point and boiling point of water under normal atmospheric pressure are chosen as reference points which are marked on the thermometer. The interval between these two points is divided into one hundred equal parts for the Celsius scale. If the freezing point of water (or) ice point is marked 0 ℃ and the boiling point of water (or) steam point is marked 100 °C, the thermometer scale is the Celsius scale. On the Celsius scale, the ice point is 0 °C and the steam point is 100 °C. On the Fahrenheit scale the ice point is 32 °F and the steam point 212 °F. On the Kelvin scale the ice point is 273 K and the steam point is 373 K.

The relationship between the Celsius temperature T_C and the Fahrenheit temperature T_F is given by the equation

$$T_C = \frac{5}{9}\,(T_F - 32) \text{ (or) } T_F = 1.8\,T_C + 32 \qquad (6.1)$$

For example, normal body temperature is 98.6 ˚F. On the Celsius scale, this is

$$T_C = \frac{5}{9}(T_F - 32)$$

$$= \frac{5}{9}(98.6 - 32)$$

$$= 37.0\ ^\circ\mathrm{C}$$

The relationship between the Celsius temperature T_C and kelvin temperature T_K is given by

$$T_C + 273 = T_K. \qquad (6.2)$$

Example (1) The room temperature is found to be 27 ˚C. What is the temperature in kelvin?

$T_C = 27\ ^\circ\mathrm{C}$

$T_K = T_C + 273$

$= 27 + 273$

$= 300\ \mathrm{K}$

Example (2) The lowest air temperature recorded in the world is 184 K. This temperature was measured in Antarctica in 1983. What is the temperature in degree Celsius?

$T_K = 184\ \mathrm{K}$

$T_K = T_C + 273$

$T_C = T_K - 273$

$= 184 - 273$

$= -89\ ^\circ\mathrm{C}$

Reviewed Exercise

- What temperature on the celsius scale corresponding to 104 ˚F, the body temperature of the person who is gravely ill?

Key Words: body temperature, room temperature, freezing point, boiling point.

6.4 THERMAL EXPANSION OF SUBSTANCES

When a substance is heated, its volume usually increases. The dimensions of the substance increase correspondingly. This increase in size can be explained in terms of the increased kinetic energy of the molecules. The additional kinetic energy results in each molecule colliding more forcefully with its neighbours. Therefore, the molecules push each other further apart and the substance which is heated increases in size.

Increasing the temperature of a gas at constant pressure cause the volume of the gas to increase. This increase occurs not only for gases, but also for liquids and solids. In general, if the temperature of a substance increases, so does its volume. This phenomenon is known as thermal expansion.

You may have noticed that the concrete roadway segments of a sidewalk are separated by gaps. This is necessary because concrete expands with increasing temperature. Without these gaps, thermal expansion would cause the segments to push against each other, and they would eventually buckle and break apart.

Linear Expansion

Although two different metal bars of the same length are heated such that the increase in temperature is the same, the magnitudes of their expansion may not be the same. For example, the expansion of copper is one and a half times that of steel. Aluminium expands twice as much as steel does.

The dependence of the change in length of an object on its original length and change in temperature is

$$\Delta l \propto l\,\Delta T$$

$$\Delta l = \alpha\, l\, \Delta T$$

$$\alpha = \frac{\Delta l}{l} \times \frac{1}{\Delta T}$$

$$l' = l(1+\alpha\,\Delta T) \qquad (6.3)$$

where Δl = change in length

ΔT = change in temperature

α = coefficient of linear expansion

l = original length of the object

l' = length of the object at $T + \Delta T$

The coefficient of linear expansion is the change in length per unit length for one degree change in temperature.

The unit of α is per K, which can be written as K^{-1}. The value of α for some materials are given in Table 6.1.

Table 6.1 The value of α for some materials

Material	α (K^{-1})
Celluloid	1.09×10^{-4}
Steel	1.27×10^{-5}
Copper	1.70×10^{-5}
Aluminium	2.30×10^{-5}
Diamond	1.00×10^{-6}
Glass	8.30×10^{-6}
Platinum	8.90×10^{-6}

The relationship between the Celsius temperature T_C and the Fahrenheit temperature T_F is given by the equation

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For example, normal body temperature is 98.6 ˚F. On the Celsius scale, this is

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$T_C = 27\ ˚\text{C}$

$T_K = T_C + 273$

$= 27 + 273$

$= 300\ \text{K}$

Example (2) The lowest air temperature recorded in the world is 184 K. This temperature was measured in Antarctica in 1983. What is the temperature in degree Celsius?

$T_K = 184\ \text{K}$

$T_K = T_C + 273$

$T_C = T_K - 273$

$= 184 - 273$

$= -89\ ˚\text{C}$

Reviewed Exercise

- What temperature on the celsius scale corresponding to 104 ˚F, the body temperature of the person who is gravely ill?

Key Words: body temperature, room temperature, freezing point, boiling point.

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$$\Delta l = \alpha\, l\,\Delta T$$

$$\alpha = \frac{\Delta l}{l}\times\frac{1}{\Delta T}$$

$$l' = l(1+\alpha\,\Delta T) \qquad (6.3)$$

where Δl = change in length
ΔT = change in temperature
α = coefficient of linear expansion
l = original length of the object
l' = length of the object at $T + \Delta T$

The coefficient of linear expansion is the change in length per unit length for one degree change in temperature.

The unit of α is per K, which can be written as K^{-1}. The value of α for some materials are given in Table 6.1.

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Aluminium	2.30×10^{-5}
Diamond	1.00×10^{-6}
Glass	8.30×10^{-6}
Platinum	8.90×10^{-6}

The following example (3) illustrates the importance of linear expansion.

Example (3) One roadbed of a steel bridge is 12.80 m long. If the temperature varies from 25 °C to 35 °C during a day, what is the difference in lengths at those temperatures? The road is supported by steel girders. For steel, $\alpha = 1.27 \times 10^{-5}\ \text{K}^{-1}$.

$l = 12.80$ m, $\alpha = 1.27 \times 10^{-5}\ \text{K}^{-1}$

$$\Delta T = 35\ ^\circ\text{C} - 25\ ^\circ\text{C}$$
$$= 10^\circ\text{C} = 10\ \text{K}$$

Here we write $\Delta T = 10^\circ\text{C} = 10$ K, since $\Delta T = (35 + 273) - (25 + 273)\ \text{K} = 10\ \text{K}$

$$\Delta l = \alpha\, l\, \Delta T$$
$$= 1.27 \times 10^{-5} \times 12.80 \times 10$$
$$= 0.001\,62\ \text{m} \text{ or } 0.162\ \text{cm}$$

Hence, the change in the roadbed length due to linear expansion must be allowed for the design of the bridge so as not to damage the bridge.

Example (4) The length of a metal bar having coefficient of linear expansion α is l at the temperature T. What is the length of that metal bar at the temperature $T + \Delta T$?

The change in length due to the temperature change ΔT is

$$\Delta l = \alpha\, l\, \Delta T$$

Therefore, the length of the metal bar at $T + \Delta T$ is

$$l' = l + \Delta l$$
$$= l + \alpha\, l\, \Delta T$$
$$= l\,(1 + \alpha\, \Delta T)$$

Area Expansion and Volume Expansion

The relations analogous to the one which gives the increase in length Δl for the increase in temperature ΔT can be derived for the area expansion and volume expansion. The relations obtained are

$$\Delta A = \beta\, A\, \Delta T \text{ (for area expansion)} \quad (6.4)$$

and

$$\Delta V = \gamma\, V\, \Delta T \text{ (for volume expansion)} \quad (6.5)$$

In these equations, β is the coefficient of area expansion and γ is the coefficient of volume expansion.

The coefficient of area expansion of a substance is the change in area per unit area for one degree change in temperature.

The coefficient of volume expansion of a substance is the change in volume per unit volume for one degree change in temperature.

Anomalous Expansion of Water

Generally all substances expand on heating and contract on cooling. But in the case of water the behavior is different, when water at 0°C is heated its volume decreases up to 4 °C and density increases. At 4°C the density becomes maximum and beyond this temperature volume start to increase. This unusual expansion of water is called anomalous expansion of water.

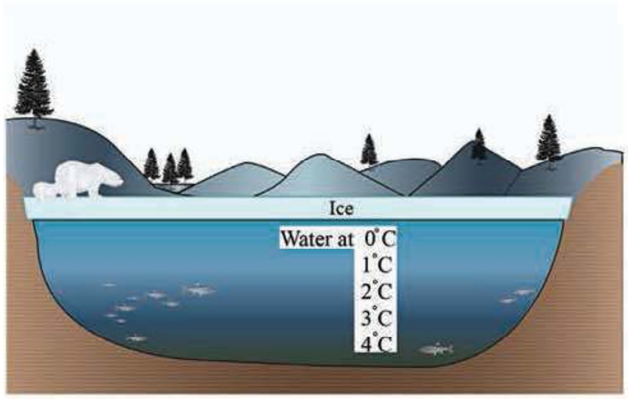


Figure 6.3 Temperature in an ice covered lake

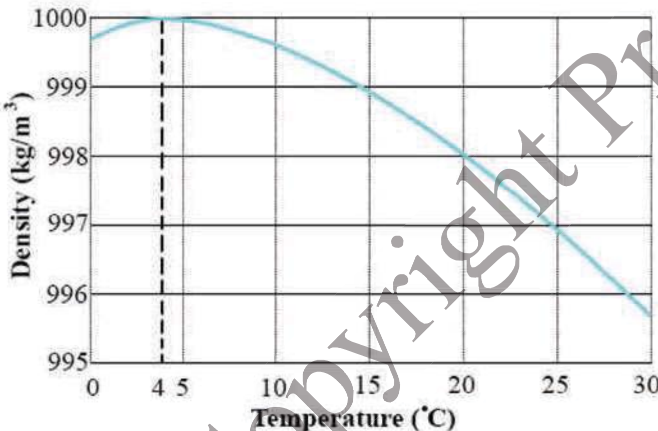


Figure 6.4 The change in density of water with temperature

Example (5) The area of a metal plate is A_1 at the temperature T_1 and A_2 at T_2. If $T_2 > T_1$, obtain the relation between A_1 and A_2. The coefficient of area expansion of metal is β.

$$\Delta A = A_2 - A_1$$

$$\Delta T = T_2 - T_1$$

Since $\Delta A = \beta A \Delta T$

$$A_2 - A_1 = \beta A_1 (T_2 - T_1)$$

$$A_2 = A_1 [1 + \beta (T_2 - T_1)]$$

Reviewed Exercise

- Obtain the relationship between the coefficient of linear expansion and the coefficient of area expansion of a substance.

Key Words: thermal expansion, anomalous expansion

SUMMARY

Temperature is a measure of hotness (or) coldness of a body.

Heat is a form of energy. It is the energy exchanged between an object and its surrounding due to different temperatures.

Coefficient of linear expansion is defined as the change in length (of a substance) per unit length for one degree change in temperature.

Coefficient of area expansion is defined as the change in surface area (of a substance) per unit area for one degree change in temperature.

Coefficient of volume expansion is defined as the change in volume (of a substance) per unit volume for one degree change in temperature.

EXERCISES

1. Complete the sentences below using words from the following list.

   expansion, temperature, voltage

   (a) The degree of hotness of an object is a measure of its ________ .

   (b) The liquid-in-glass thermometer makes use of the ________ of the liquid when its ________ changes.

   (c) In a thermocouple thermometer, a change of ________ causes its ________ to change.

2. (a) A liquid-in-glass clinical thermometer is marked with a scale from 32°C to 42°C which covers a distance of 80 mm. A liquid-in-glass laboratory thermometer is marked with a scale from 0 °C to 100 °C, which covers a distance of 160 mm. State and explain which thermometer; (i) has the greater range, (ii) is more sensitive.

   (b) The following results were obtained when the voltage of a thermocouple thermometer was measured at different temperatures.

Voltage (millivolt)	0	1.4	2.8	4.3	5.7	6.9
Temperature (°C)	0	20	40	60	80	100

   (i) Plot a graph of the voltage on the y-axis against temperature in °C on the x-axis.

   (ii) Use the graph to determine the voltage at 50°C and the temperature at 5.0 mV.

3. A solid expands when heated. What happens to its (a) mass, (b) volume, (c) density?

4. If the unit of the coefficient of linear expansion is changed from per K to per °F, does the numerical value of that coefficient change?

5. If the temperature of a room is found to be 30 °C, what is the room temperature as measured on the Kelvin scale?

6. The coefficient of volume expansion of Pyrex glass is one-third that of ordinary glass. Which glass can stand more thermal strain?

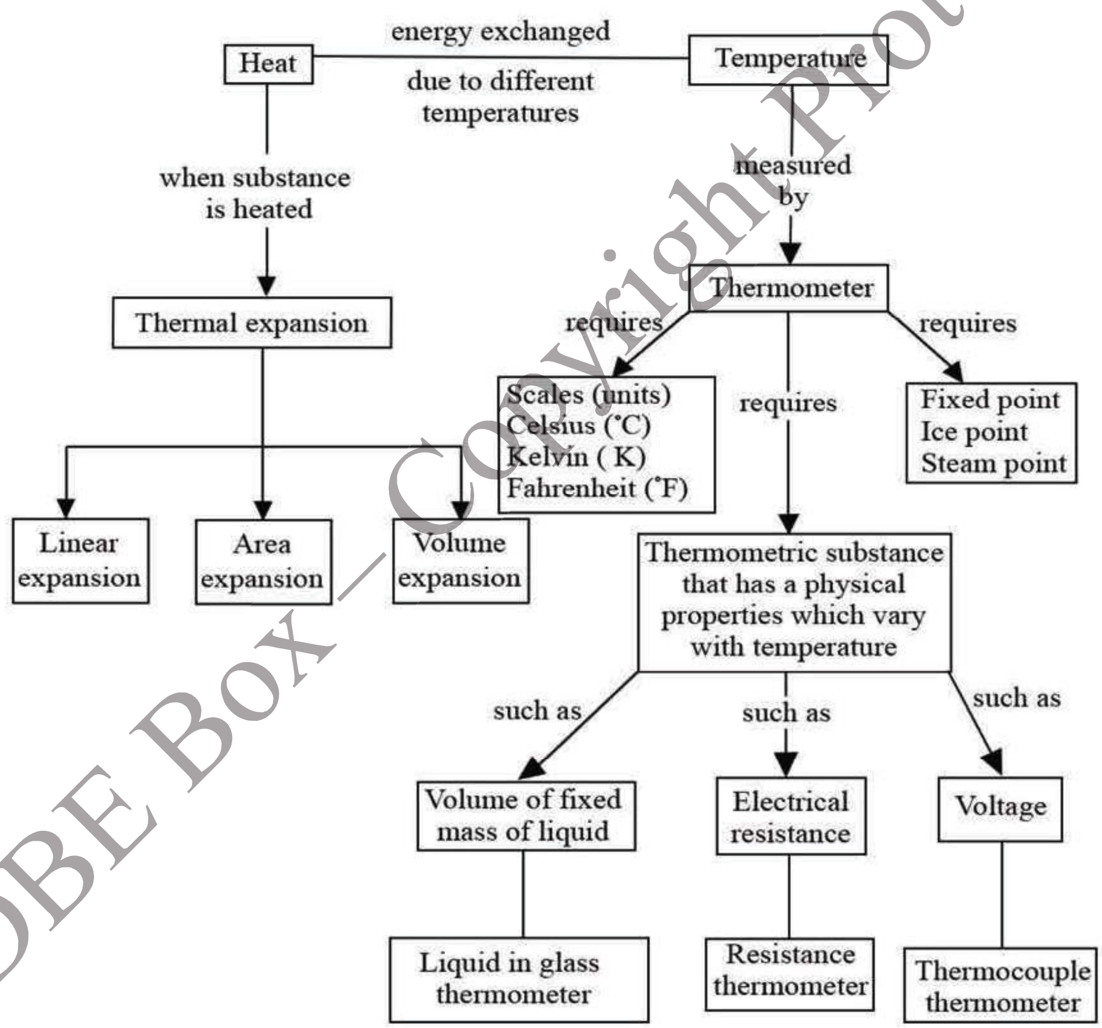
7. At what temperatures are the readings on the Fahrenheit and Celsius scales the same?

8. A steel railroad track is 20 m long at 20 °C. How much longer is it at 40 °C? (The coefficient of linear expansion of steel is $1.27 \times 10^{-5}\ K^{-1}$)

9. A steel railroad track is 30 m long at 0 °C. How much shorter is it at –20 °C? (The coefficient of linear expansion of steel is $1.27 \times 10^{-5}\ K^{-1}$)

10. A heat-resistant glass at 15 °C is fully filled with 250 cm^3 of glycerine. If the temperature increases to 25 °C how much glycerine overflows? The coefficient of volume expansion of glycerine is $5.1 \times 10^{-4}\ K^{-1}$ and that of heat-resistant glass is $0.09 \times 10^{-4}\ K^{-1}$

CONCEPT MAP



CHAPTER 7

WAVE AND SOUND

When we think of the word waves, water wave on the water surface of a pond and sea waves usually come to mind. Besides these waves there are other types of wave such as sound wave, radio waves, etc. Wave is a basic concept of physics. Energy and momentum are transferred through the medium from the wave source. All waves are produced by a vibrating source.

Learning Outcomes

It is expected that students will

- examine wave motion as a form of energy transfer.
- compare transverse and longitudinal wave and give suitable examples of each.
- illustrate displacement-time graph and displacement-position graph.
- express the concept of wave equation and use it to solve problems.
- describe the reflection, refraction and diffraction of waves.
- apply the basic knowledge of generation, propagation and hearing of sound in daily life.

7.1 DESCRIBING WAVE MOTION

Wave motion is a method of transferring energy by successive disturbances through the medium. This movement of energy takes place without transferring matter.

For examples, (1) Waves are produced if you drop a stone onto a quiet surface of a pond. The waves spread out from the point of impact, carrying energy to all parts of the pond (Figure 7.1). But the water in the pond does not move from the centre to the edges. This shows that wave transfer energy without transferring matter.

Figure 7.1 Water wave on the surface of a pond [Physics Matter]

(2) Waves can be produced along a rope by fixed end and moving the other end up and down rapidly shown in Figure 7.2. It can be seen that the rope waves move toward the fixed end, while the rope segments only vibrate up and down about their rest (equilibrium) position. The energy from hand is transferred by the rope waves toward the fixed end. The rope is the medium through which the waves move.

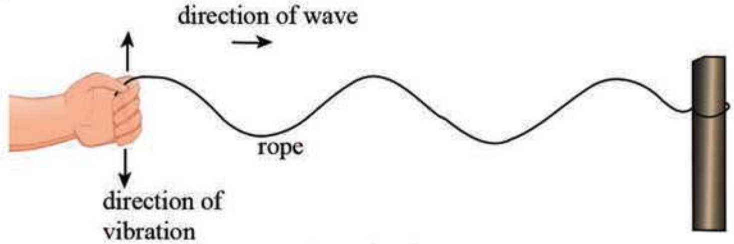


Figure 7.2 Producing wave on a rope

There are two types of waves. They are mechanical waves and electromagnetic waves. The mechanical waves need material medium to propagate and cannot pass through vacuum.

> Sound waves and seismic waves, which are produced by an earthquake, are mechanical waves. Electromagnetic waves can pass through vacuum and they do not need medium for propagation. Light wave and X-rays are electromagnetic waves.

Reviewed Exercise

- Give examples of mechanical and electromagnetic waves.

Key Words: disturbance, energy, vibration

7.2 TRANSVERSE AND LONGITUDINAL WAVES

Waves are classified as transverse and longitudinal waves depending on vibration of particles in the medium through which they propagate.

If the displacements of particles of the medium are perpendicular to the direction of the wave, such a wave is called a transverse wave. Waves in a vibrating string are transverse waves. They can be demonstrated by moving up and down the free end of a rope (or) slinky spring which is fitted at one end as shown in Figure 7.3. Light waves and other electromagnetic waves are also transverse waves.

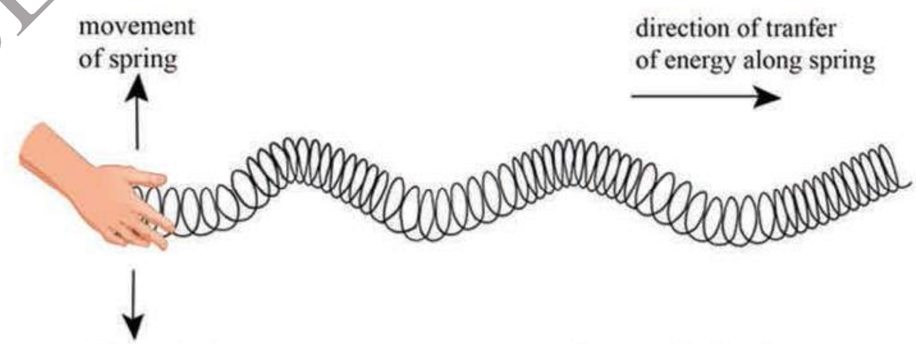


Figure 7.3 The transverse waves on slinky coiled spring

If the displacements of particles of medium are parallel to the direction of the waves, such a wave is called a longitudinal wave. Compressional waves in a slinky coiled spring and sound waves are longitudinal waves.

A longitudinal wave is demonstrated by rapidly pushing forth and pulling back at one end of a slinky coiled spring while another end is fixed. It can be seen that the back and forth movement of the coil is parallel to the wave direction as shown in Figure 7.4.

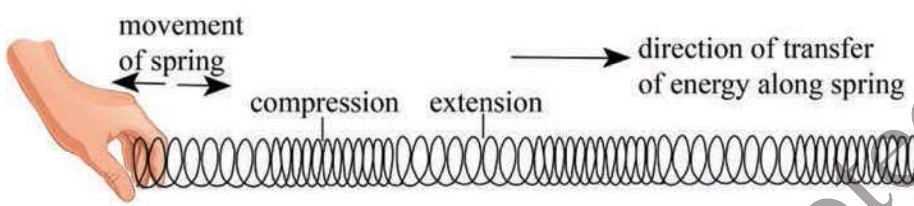


Figure 7.4 Longitudinal waves on slinky coiled spring

Some waves in nature exhibit a combination of transverse and longitudinal waves. Water waves are good example of combinational waves.

The longitudinal slinky spring wave is represented by a graph (Figure 7.5) which shows the compression and extension of spring segments. This graph is similar to the wave produced by the vibrating rope shown in Figure 7.2.

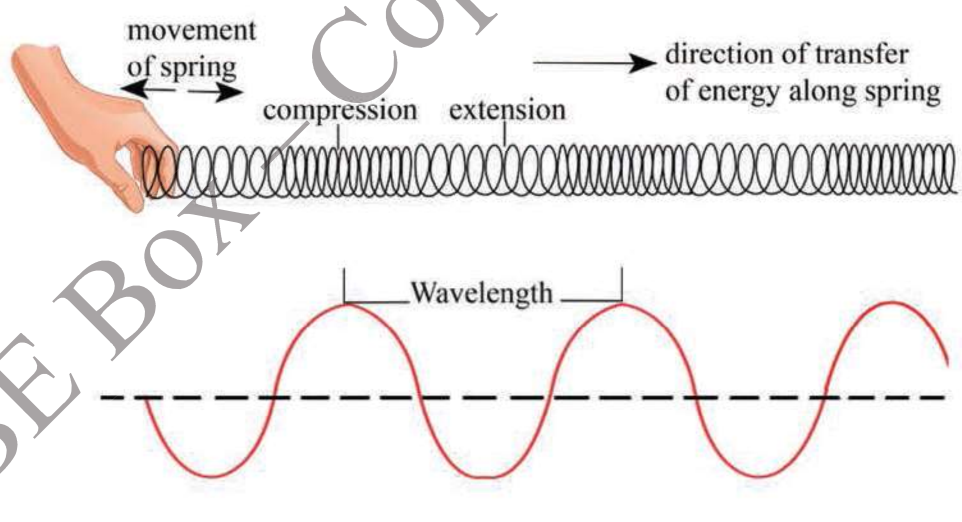


Figure 7.5 Graphical presentation of longitudinal wave

Reviewed Exercise

- Describe the similarities and differences between sound waves and water waves.

Key Words: transverse waves, longitudinal waves, compression, extension

7.3 CHARACTERISTICS OF WAVES

This section will discuss some quantities of periodic waves.

Wave Crest and Trough of Periodic Waves

The highest and the lowest points (Figure 7.6) which show the maximum displacement of vibrating particle from its rest position (or) equilibrium line are called wave crest and wave trough respectively. The arrows indicate the direction of displacement of the vibrating particle.

Wavelength (λ): The distance between any two consecutive wave crests (or) two consecutive wave troughs is called wavelength. The unit of wavelength in SI unit is metre (m).

Generally the wavelength is the distance between two nearest points of same phase.

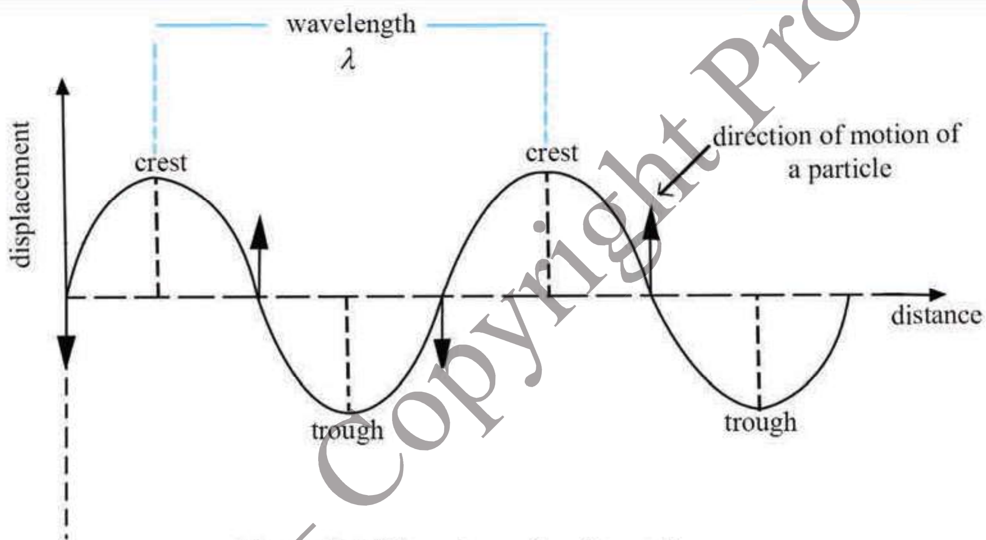


Figure 7.6 Wave in a vibrating string

Frequency (f) : The number of complete waves passing a point per second is called frequency of waves. The frequency of the wave depends on the vibrating source. The number of oscillation of a vibrating source in one second is also called frequency. The SI unit of frequency is hertz (Hz). One hertz is equal to one complete cycle per second.

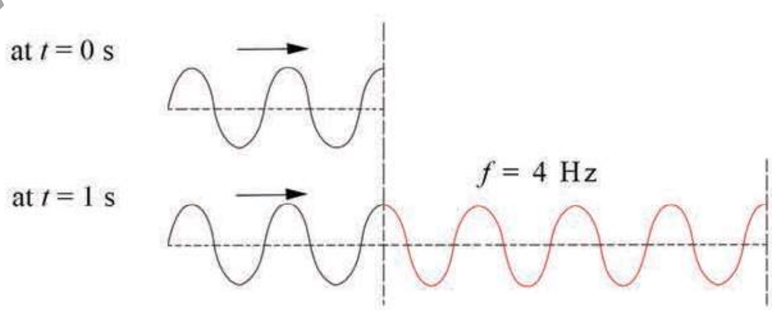


Figure 7.7 Frequency of a periodic wave (four complete waves pass a point in one second)

Period (T) : The time taken by the wave to travel the distance between any two consecutive wave crests (or) the time required for one complete vibration is called period of a wave. The unit of period is the second (s).

The period is the reciprocal or inverse of the frequency. Thus,

$$T = \frac{1}{f}$$

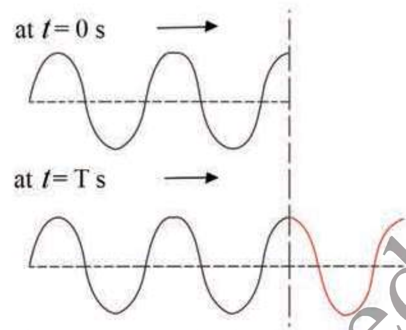


Figure 7.8 Period of the wave

Amplitude : The amplitude of a wave is the maximum value of displacement of vibrating particle. It can be seen on the wave graph shown in Figure 7.6 as the perpendicular distance from the equilibrium line to the wave crest (or) trough.

Velocity of Wave (v) : Velocity of wave is the speed with which a wave crest travels. The unit of wave velocity is metre per second (m s^{-1}).

> Most of the periodic waves are represented by sine (or) cosine graphs. Therefore they can be called sine waves.

The relationship between the frequency, wavelength and velocity of a periodic wave can be obtained by

$$\text{velocity} = \frac{\text{distance moved}}{\text{time taken}}$$

A complete wave travels through the distance equal to its wavelength in time period T.

$$\text{velocity} = \frac{\text{wavelength}}{\text{period}}$$

$$v = \frac{\lambda}{T}$$

Since ,

$$T = \frac{1}{f}$$

$$v = f\lambda$$

Reviewed Exercise

- Write down the relation between period and frequency. Explain it.

Key Words: hertz, oscillation

7.4 GRAPHICAL REPRESENTATION OF WAVE

Displacement-Distance Graph

A displacement-distance graph describes the displacement of all particles at a particular instant of time. Note that displacement of particle is plotted on y- axis and distance moved by the wave is on x - axis.

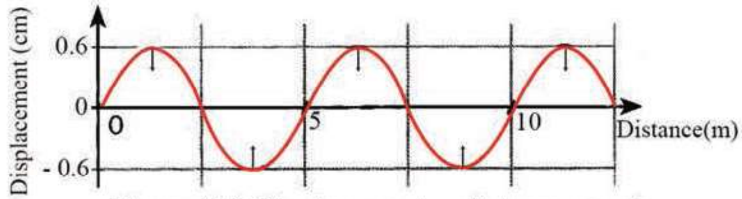


Figure 7.9 Displacement – distance graph

The arrows shown on the graph indicate the direction of the displacement of vibrating particle. According to the graph the amplitude is 0.6 cm and wavelength is 5 m respectively.

Displacement-Time Graph

A displacement-time graph describes the displacement of particle of a certain position as a function of time taken to travel by a wave. Note that displacement of particle is on Y axis and time interval is on X axis.

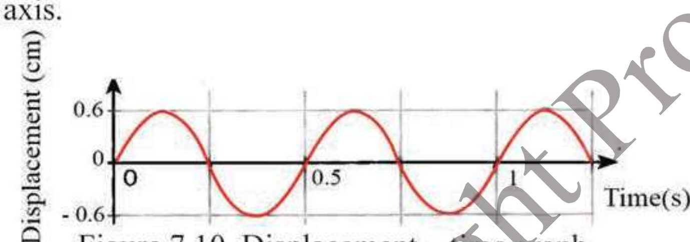


Figure 7.10 Displacement – time graph

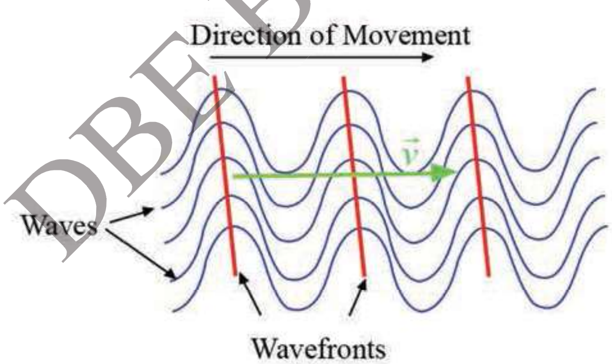
According to the graph, the amplitude and the period of the wave are 0.6 cm and 0.5 s respectively. Since $T = \frac{1}{f}$, the frequency of the wave is 2 Hz.

7.5 REFLECTION, REFRACTION AND DIFFRACTION OF WAVE

Wave can undergo reflection, refraction and diffraction. These phenomena are usually studied by means of water wave in a ripple tank.

Ripple Tank : The ripple tank is a convenient piece of apparatus for demonstrating the properties of waves.

Wavefront : The surface that joins all the points of same phase is called wavefront.



(a)

(b)

Figure 7.11 The wavefronts of (a) plane wave and (b) circular waves

Reflection

When a series of wave strike an obstacle, they are turned back. This turning back of waves is called reflection of waves. When waves strike a straight barrier, the waves are reflected from the barrier. The angle of incidence is equal to the angle of reflection as shown in Figure 7.12. The wavelength and velocity of the wave remain constant in reflection of wave.

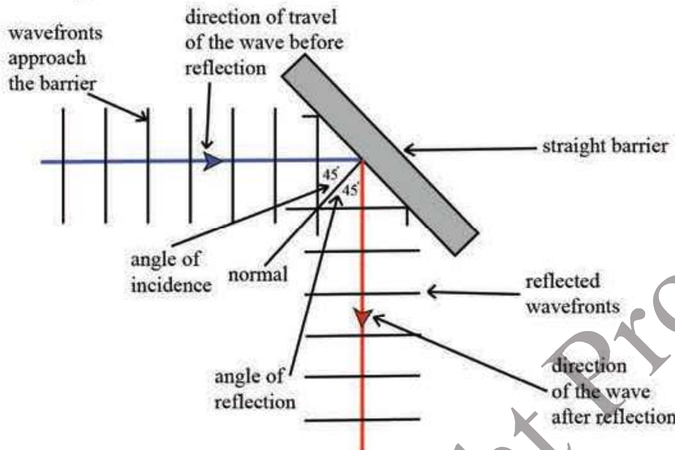


Figure 7.12 Reflection of plane wave

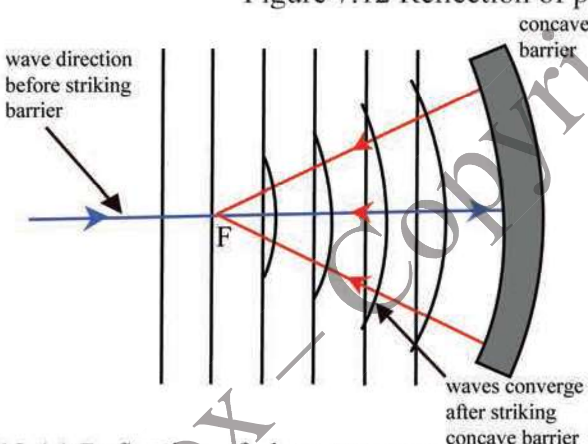


Figure 7.13 (a) Reflection of plane wave on concave surface

Figure 7.13 (b) Radio antenna
[https://en.m.wikipedia.org/wiki/yevpatoria-RT-70-radio-telescope]

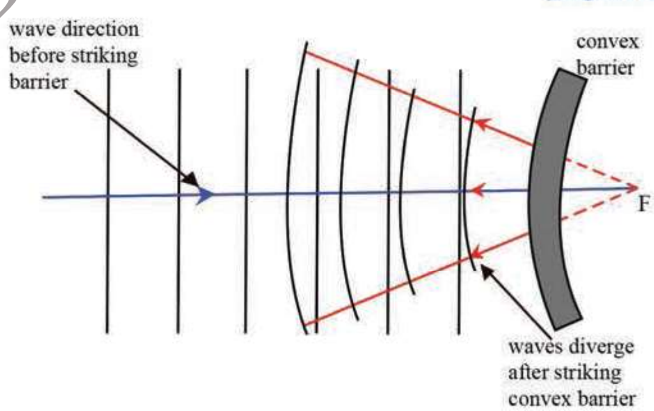


Figure 7.14 Reflection of plane wave on convex surface

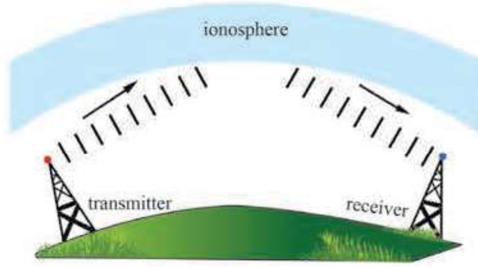


Figure 7.15 Reflection of radio waves

Refraction

The speed of water waves depends on the depth of water. It decreases when the depth of water becomes less deep. By the ripple tank experiment, when water waves pass from deep to shallow water the velocity of wave is lesser and the wavelength is shorter or vice-versa. When waves are incident to the boundary with an angle, the direction of the waves changes. Such a change in direction is called refraction. It can be noticed that in refraction, the wavelength and velocity change but frequency remains the same.

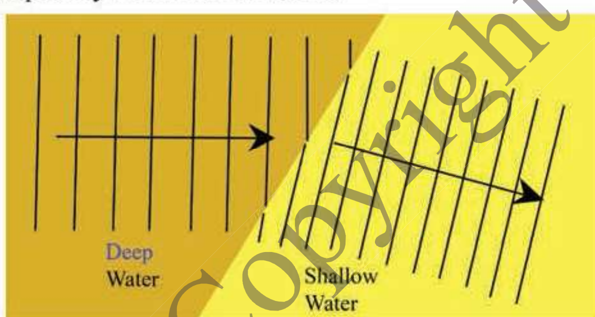


Figure 7.16 Refraction of plane wave

Diffraction

Diffraction is the spreading of waves from the straight-on direction through a gap (or) moves around an obstacle. The wave that passes the edges of the gap of the obstacle spread out. Figure 7.17 and 7.18 show water waves in ripple tank spreading out after they pass through the gap. In Figure 7.17 the wider the gap, the less the waves spread out. In Figure 7.18 the narrower the gap, the more the waves spread out. Note that the wavelength does not change after diffraction.

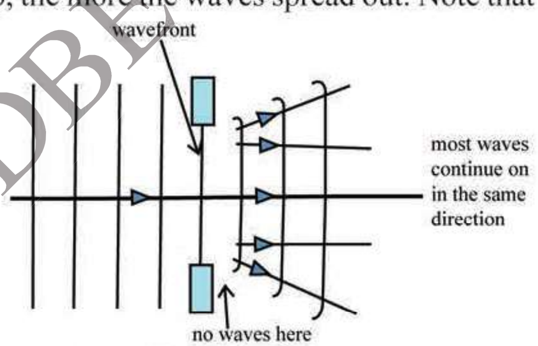


Figure 7.17 Diffraction of water waves through wide gap

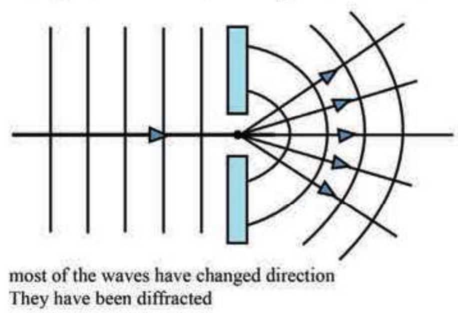


Figure 7.18 Diffraction of water waves through narrow gap

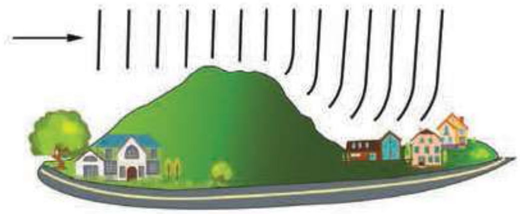


Figure 7.19 Diffraction of radio waves

Diffraction around an obstacle includes radio waves that are diffracted as they pass over the hill. (Figure 7.19)

Reviewed Exercise

1. What causes refraction of water waves?
2. Does the speed of water waves depend upon the depth of water?

Key Words: ripple tank, wavelength

7.6 SOUND WAVE AND SPEED OF SOUND

Sound Wave

Sound is a form of energy that is transferred from one place to another in a certain medium. Sound wave is produced by a vibrating object placed in a medium. The pressure changes occur alternately in the medium by vibrating object. The medium is usually air, but it can be any gas, liquid (or) solid. Sound wave propagates as a series of compression and rarefaction like longitudinal waves on a vibrating spring. Like other waves, sound wave can be reflected and diffracted.

> Unlike electromagnetic waves, sound waves need a medium to propagate. Sound wave cannot travel through vacuum.

The compression is created in the medium as the vibrating object moves forward, since it pushes molecules together. The compression region has higher pressure. When the object moves back, the molecules are spread out and rarefaction is created and the pressure of that region is low. After the object is vibrated several times, it has created a series of compression and rarefactions travelling away from the vibrating object. The pressure of the medium is changed into higher and lower alternately. In this way, sound energy propagates through the medium to the ear. When waves enter the ear, they strike the ear drum and make it vibrate. This vibration of ear drum results the hearing of the sound. Sound energy is transferred through the medium by the successive pressure changes among the adjacent parts without moving the medium as a whole.

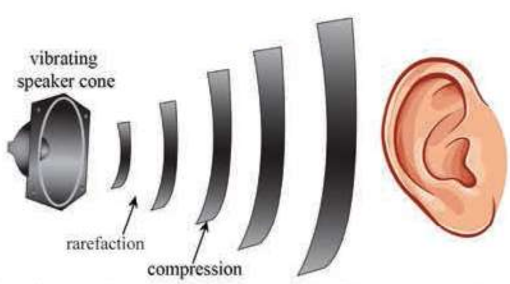


Figure 7.20 Vibrating loud speaker produces sound wave and travels through air to ear

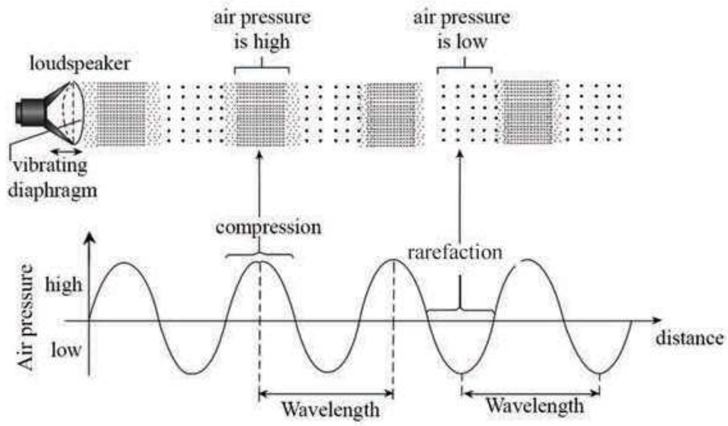


Figure 7.21 Pressure-distance graph of a propagated sound waves

Audible range : The average person can only hear sound that has a frequency higher than 20 Hz and lower than 20 000 Hz. This interval of frequency is called the audible range (or) hearing range. But the range becomes reduced according to age and health conditions. Sound waves with frequencies greater than 20 000 Hz are called ultrasounds. Some objects vibrating with frequencies under 20 Hz produces sound which cannot be heard by human. This is called infrasound.

It is found that, by experiments: dog, bat and dolphin can hear the ultrasound and they communicate with it. On the other hand, elephants can communicate with infrasound.

Speed of Sound

Since sound propagates from one place to another through a distance in a time interval in a given medium, the speed of sound is

$$\text{speed of sound} = \frac{\text{distance travelled by sound}}{\text{time taken}}$$

$$v = \frac{d}{t}$$

However, sound waves travels at different speeds in different media through which it passes. Generally, the speed of sound depends on the density of the medium. The denser the medium is, the greater the speed because the particles of the medium are tightly bound together. This means that the disturbance can be transferred more quickly from one particle to next.

Table 7.1 The speed of sound in some solids, liquids and gases

Medium	**Speed**		**Temperature °C**
	$m\ s^{-1}$	$ft\ s^{-1}$	
Air	332	1090	0
CO_2	259	850	0
Cl_2	206	676	0
Water, pure	1 404	4 605	0
Copper	3 560	11 680	20
Iron	5 130	16 830	20

Speed of sound in air varies with temperature. At 0°C the speed of sound in air is 332 m s^{-1}. Whenever the air temperature increases by 1°C, speed of sound will increase by 0.2 %. The speed of sound in air can be expressed as

$$v = 332\sqrt{\frac{T}{273}}$$

Here T is given in K and v in ms^{-1}. The above relation can be approximated by

$$v \cong 332 + 0.6\,(T - 273)$$

In air medium, the speed of sound increases by 0.6 m $s^{-1}$with temperature rise by one degree (1°C or 1 K).

Example (1) A distance of 0.33 m separates a wave crest from the adjacent trough, and the vertical distance from the top of a crest to the bottom of a trough is 0.24 m. What is the wavelength? What is the amplitude?

The wavelength, $\lambda = 2 \times 0.33 = 0.66$ m

The amplitude, $A = \dfrac{0.24}{2} = 0.12$ m

Example (2) What is the speed of a 256 Hz sound with a wavelength of 1.35 m?

The speed of sound $v = f\lambda = (256)\,(1.35) = 346$ m s^{-1}

Example (3) You dip your finger into a pan of water 14 times in 11s, producing wave crests separated by 0.16 m. (a) What is the frequency? (b) What is the period? (c) What is the velocity?

(a) The frequency, $f = \dfrac{14}{11} = 1.27$ Hz

(b) The period, $T = \dfrac{1}{f} = \dfrac{1}{1.27} = 0.79$ s

(c) The velocity, $v = f\lambda = (1.27)\,(0.16) = 0.20$ m s^{-1}

Example (4) A tall tree sway back and forth in the breeze with frequency of 2 Hz. What is the period of this?

The period, $T = \dfrac{1}{f} = \dfrac{1}{2} = 0.5$ s

Example (5) A typical sound wave associated with human speech has a frequency of 500 Hz and the frequency of the yellow light is about 5×10^{14} Hz. The velocity of sound in air is 344 m s^{-1} and the velocity of light is 3×10^{8} m s^{-1}. Find the wavelengths of the waves.

For the sound wave, $\lambda = \dfrac{v}{f} = \dfrac{344}{500} = 0.688$ m

For the light wave, $\lambda = \dfrac{c}{f} = \dfrac{3 \times 10^{8}}{5 \times 10^{14}} = 6 \times 10^{-7}$ m = 6 000 Å

Example (6) On a day when air temperature is 11ºC, you use a whistle to call your dog. If the wavelength of the sound produced is 0.015 m, what is the frequency? Could you hear the whistle?

The velocity of sound in air at 11 ºC is

$$v = 332\sqrt{\frac{T}{273}}$$

$$= 332\sqrt{\frac{273+11}{273}} = 332\sqrt{1.04} = 332 \times 1.02$$

$$= 338.62 \text{ m s}^{-1}$$

$$f = \frac{v}{\lambda} = \frac{338.62}{15 \times 10^{-3}}$$

$$= 22.57 \times 10^{3} \text{ Hz}$$

$$= 22\,570 \text{ Hz}$$

We could not hear the whistle (sound) because the human's ear is supposed to be able to hear sound with frequency that are greater than 20 Hz and less than 20 000 Hz.

Reviewed Exercise

1. How does the velocity of sound depend on the temperature of the medium through which its travels?
2. 'Generally, the denser the medium the greater will be the velocity of sound'. Explain this statement.

Key Words: compression, rarefaction, ultrasound, infrasound, frequency

SUMMARY

Transverse wave: If the displacements of particles of the medium are perpendicular to the direction of the wave, such a wave is called transverse wave.

Longitudinal wave: If the displacements of particles of medium are parallel to the direction of the waves, such a wave is called longitudinal wave.

Wavelength (λ): The distance between any two consecutive wave crests (or) two consecutive wave troughs is called wavelength.

Frequency (f): The number of complete waves passing a point per second is called frequency of waves.

Period (T): The time taken by the wave to travel the distance between any two consecutive wave crests (or) the time required for one complete vibration is called period of a wave.

Amplitude: The amplitude of a wave is the maximum value of displacement of vibrating element.

Velocity of wave (v): Velocity of wave is the speed with which a wave crest travels.

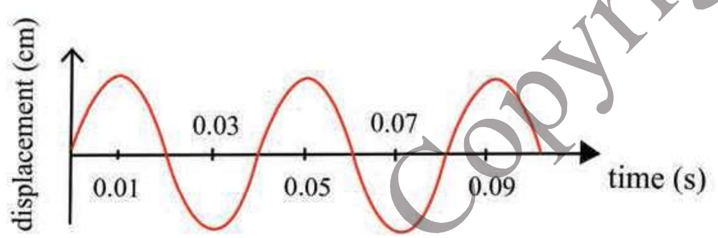
EXERCISES

1. Sound waves can travel in all the following except
   A. solids C. air
   B. liquids D. vacuum

2. How does the speed of sound vary in the following media; water, air and wood?

	Highest speed	Lowest speed
A.	Air	water
B.	Water	wood
C.	Wood	water
D.	Wood	air

3. Which one of the following statements is true for both sound and light waves?
   A. They are transverse waves.
   B. They are reflected from a glass surface.
   C. They travel faster in air than in water.
   D. They are electromagnetic waves.

4.


   The displacement of an air particle with time as a sound wave travels through the air is as shown above.
   What is the frequency of the sound wave?
   A. 10 Hz C. 50 Hz
   B. 25 Hz D. 100 Hz

5. Which of the following is the normal audible frequency range of a human ear?
   A. 0 - 10 000 Hz C. 20 - 20 000 Hz
   B. 0 - 20 000 Hz D. 100 - 100 000 Hz

6. Which of the following frequencies of sound cannot be detected by the human ear?
   A. 50 Hz C. 50 00 Hz
   B. 500 Hz D. 50 000 Hz

7. A sound of frequency 400 Hz has a wavelength of 4.0 m in a medium. What is the speed of sound in the medium?

   A. 10^{-2} ms^{-1} C. 1 600 ms^{-1}

   B. 100 ms^{-1} D. 8 000 ms^{-1}

8. A boy hears the thunder 2.0 s after seeing lighting flash. How far is the lighting flash from the boy? (Speed of sound $= 330\ ms^{-1}$)

   A. 165 m C. 660 m

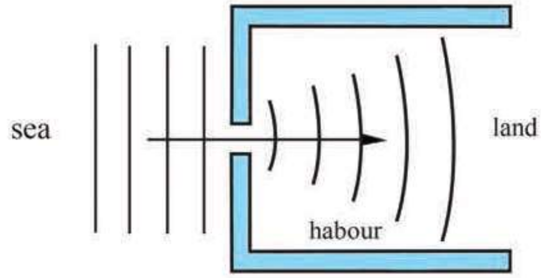
   B. 330 m D. 1320 m

9. Which of the following describes correctly the changes, if any, to the frequency, wavelength and speed of sound as is travels from air into water?

Frequency	Wavelength	Speed
A. Remains unchanged	decreases	decreases
B. Remains unchanged	increases	increases
C. Increases	increases	increases
D. Increases	remains unchanged	decreases

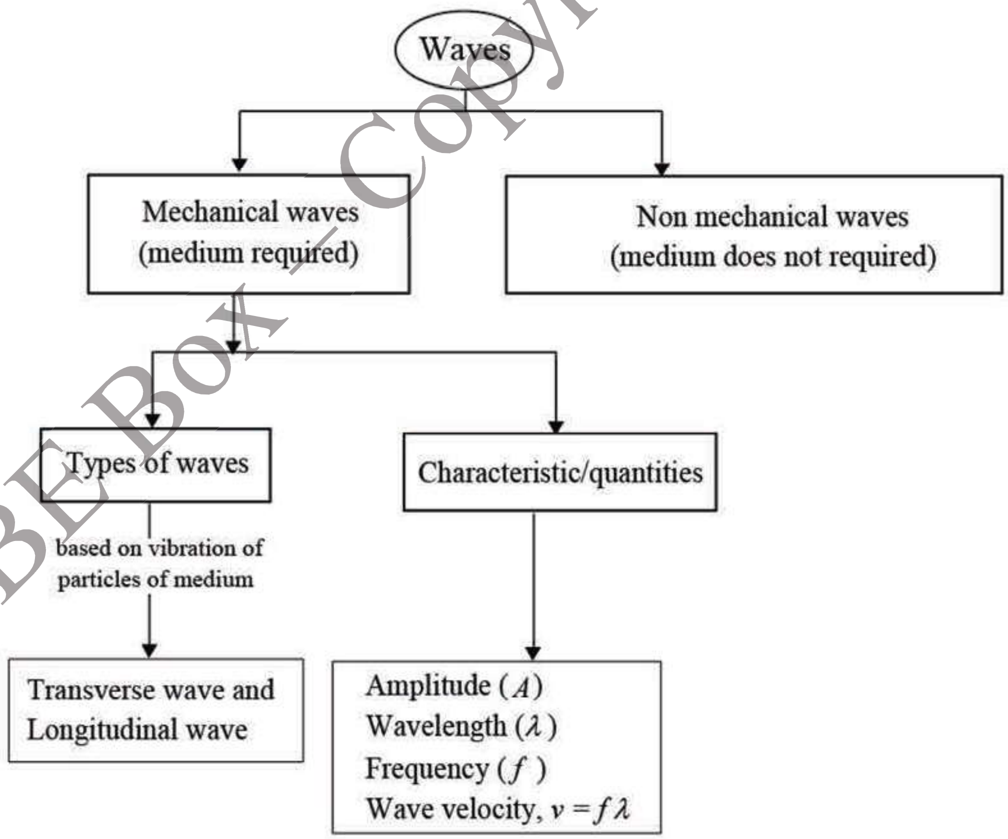
10. Define wavelength, frequency and velocity of a sound wave. Write down the relationship between them. Can this relationship be used for other waves (such as light waves)?
11. What are wavefronts?
12. What is meant by (a) reflection (b) refraction and (c) diffraction?
13. Are the following statements true (or) false? Correct the statements which are wrong.
    (a) The frequency of a wave is directly proportional to its wavelength.
    (b) Sound wave is transverse wave and water wave is longitudinal wave.
    (c) The velocity of sound is the same in water, air and helium gas.
    (d) Sound waves cannot travel through vacuum.
14. Find the wavelength of a wave with frequency 1 000 Hz and velocity 344 m s^{-1}.
15. Find the frequency of a wave of velocity 200 m s^{-1} and wavelength 0.5 m.
16. A radar antenna emits electromagnetic radiation ($c = 3 \times 10^8$ m s^{-1}) of wavelength 0.03 m for 0.5 s. (a) Find the frequency of radiation. (b) How many complete waves are emitted in 0.5 s?
17. Find the frequency of a wave of 29 m wavelength telecast by a TV station. The velocity of that wave is the same as that of other electromagnetic waves and is 3×10^8 m s^{-1}.
18. The shortest wavelength of an ultrasonic wave emitted by a bat (in air at 0°C) is 3.3 mm. What is the frequency of this wave? Is this frequency the largest (or) the smallest?
19. The frequency of a musical note in air is 440 Hz. What is the wavelength of that sound in sea water and in CO_2 gas? (Velocity of sound in sea water and CO_2 gas is 1 440 m s^{-1} and 259 m s^{-1} respectively.)

20. What is the velocity of sound in air at 20 ºC?
21. If the temperature of the air medium is increased from 0 ºC to 40 ºC, by what percentage has the velocity of sound increased?
22. The diagram below shows water waves passing through the entrance of a model harbour.



(a) Describe what happens to the waves as they leave gap between the harbour walls.
(b) What is this process called?
(c) Describe one change that could be made to the above arrangement in order to reduce this effect.

CONCEPT MAP



CHAPTER 8

LIGHT

When light travels through a uniform medium, whether it is vacuum, air (or) water, it always travels in a straight line. However, when the light encounters a different medium, some part of the light is absorbed, some is reflected and the rest is transmitted.

Learning Outcomes

It is expected that students will

- identify sources of light.
- examine the laws of reflection and the reflection of light at plane and curved surfaces.
- apply basic knowledge of optics to optical phenomena.
- draw ray diagrams for reflection of light on plane and curved surfaces.

The study of nature and propagation of light is known as optics. Optics is divided into two parts: geometrical optics and physical optics.

Geometrical optics is based upon the fact that light travels in a straight line. Ray diagrams are used in explaining the optical phenomena. On the other hand, physical optics is based upon the fact that light propagates by means of a wave-motion. Of these two, only geometrical optics will be studied in this chapter.

8.1 SOURCES OF LIGHT

Some objects such as the sun, the stars, fluorescent lamps and candles make their own light. These sources are called luminous sources. Most objects do not emit their own light but reflect light from luminous sources. They are non-luminous objects.

The sun is the chief source of light. The fact that light coming from the sun passes through the empty space on its way to the earth shows that light can travel through vacuum.

The speed of light has a definite value. All the forms of electromagnetic radiation, including light, travel at a speed of 3×10^8 m s^{-1} in a vacuum. This speed is about one million times faster than that of sound.

Key Words: luminous, vacuum

8.2 REFLECTION OF LIGHT

When light is incident on the surface of an object some of the light is sent back and this phenomenon is called reflection of light. A ray of light is a path along which the light travels. A ray is represented by a straight line with an arrow-head. The arrow-head points in the direction of propagation of light.

A beam of light is a collection of rays of light. Figure 8.1, Figure 8.2 and Figure 8.3 show the parallel rays of light, the convergent rays and the divergent rays respectively.

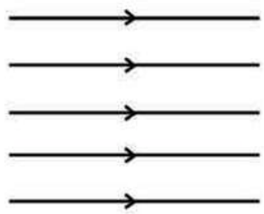


Figure 8.1 Parallel rays

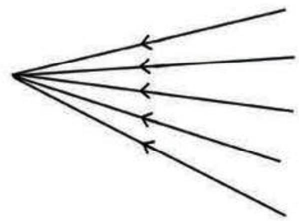


Figure 8.2 Convergent rays

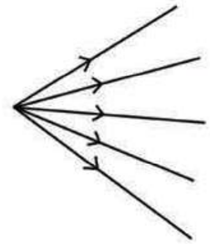


Figure 8.3 Divergent rays

Searchlights used in trains and lighthouses, emit parallel beam of light. Parallel beam of light become a convergent beam after passing through a convex lens. A beam emitted by a light bulb is a divergent beam.

In Figure 8.4, a ray which represents the incident light is an incident ray (AO). A line perpendicular to the surface at the point of incidence is called normal (NO). A ray which represents the reflected light is a reflected ray (OB). An angle between the incident ray and the normal is an angle of incidence (i) and an angle between the reflected ray and the normal is an angle of reflection (r).

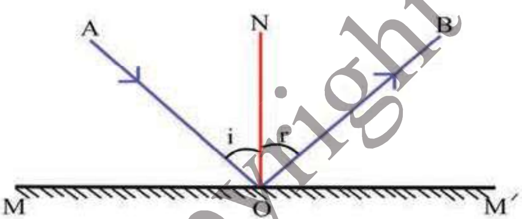


Figure 8.4 Illustration of reflection of light at a plane surface

Laws of Reflection

(1) The incident ray, the reflected ray and the normal all lie in the same plane.

(2) The angle of incidence is equal to the angle of reflection.

Laws of reflection are true for all reflecting surfaces for plane mirrors as well as curved mirrors.

Reviewed Exercise

1. Give the names of light source which emit parallel beam and divergent beam.
2. Check the laws of reflection using a plane mirror.

Key Words: divergent beam, convergent beam, parallel beam

8.3 IMAGE FORMATION IN A PLANE MIRROR

An object having a smooth reflecting surface is called a mirror. A common mirror is a plane mirror. If the reflecting surface is plane, the mirror is called a plane mirror. A looking glass is one kind of a plane mirror. Figure 8.5 (a) and Figure 8.5 (b) are shown the formation of image of a point object and an extended object due to a plane mirror.

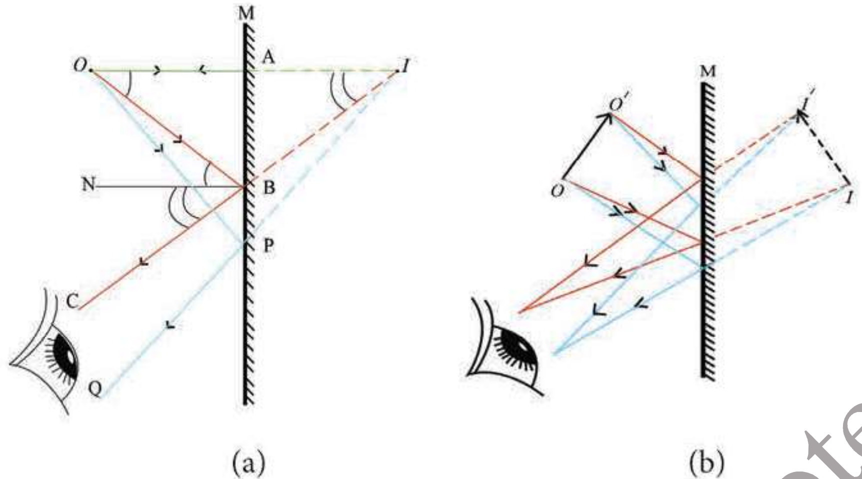


Figure 8.5 Formation of images of a point and an extended object

In Figure 8.5 (a), the image *I* is observed as the reflected rays enter the eye. The reflected rays appear to diverge from *I*. The reflected rays do not actually pass through the image; only the reflected rays produced backwards pass through it. Such an image is called virtual image. The virtual image cannot be formed on a screen. The image formed by the actual intersection of the reflected rays is a real image. A real image can therefore be focused on a screen.

In Figure 8.5 (b), II' is the image of an object OO'. The object OO' can be considered as an object formed by several point objects. I is the image of a point O and I' is that of a point O'. The points between O and O' have the corresponding images between I and I'.

Lateral Inversion

Suppose that a man is looking himself (at his image) in a looking glass. When he tilts his head to the right, the head of the image in the mirror is found to tilt to the left, and vice versa. This effect is called lateral inversion. Examples of this phenomenon are also demonstrated in Figures 8.6 and 8.7.

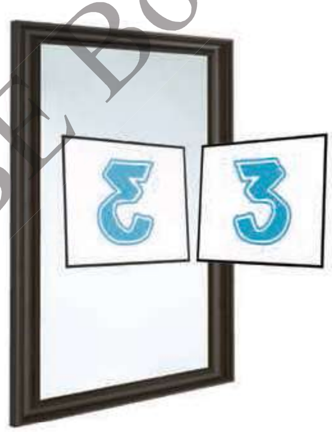


Figure 8.6 Lateral inversion of a number

Figure 8.7 Lateral inversion of a word

Properties of an Image in a Plane Mirror

The properties of an image formed in a plane mirror are as follows:

1. The image is of the same size as the object.
2. The image is virtual.
3. The image is erect.
4. The image is laterally inverted.
5. The image is situated on the line passing through the object and perpendicular to the plane mirror.
6. The image is as far behind the mirror as the object is in front.

Principle of Reversibility of Light

In Figure 8.8, if the direction of a ray of light is reversed, the light ray will travel along its original path. This is known as the principle of reversibility of light. This principle is valid also for refraction of light.

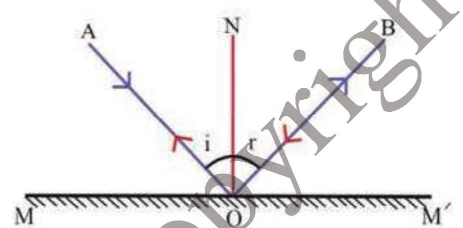
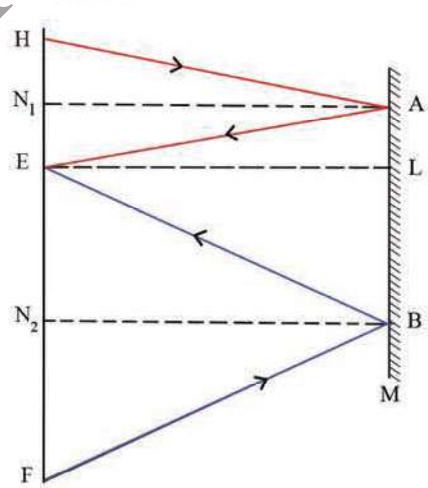


Figure 8.8 Illustration of reversibility of light

Example (1) A man 5 ft 6 in tall and whose eye level is 5 ft 2 in above the ground, looks at his image in a looking glass. What is the minimum vertical length of the looking glass if the man is to be able to see the whole of himself?



In the above Figure M is the looking glass. H represents the man's head, E his eyes and F his feet, respectively.

Therefore, HF = 66 in, EF = 62 in and HE = 66 – 62 = 4 in

For the man to be able to see his head, an incident ray from H to the top A of M must reflected to his eyes E.

Since the normal AN_1 bisects HE

$$AL = EN_1 = \tfrac{1}{2}\,HE$$
$$= \tfrac{1}{2} \times 4 = 2\text{ in}$$

For the man to be able to see his feet F, a ray from F incident at the bottom B of mirror M must be reflected to his eyes E.

Since the normal BN_2 bisects EF,

$$LB = EN_2 = \tfrac{1}{2}\,EF$$
$$= \tfrac{1}{2} \times 62 = 31\text{ in}$$

Therefore, the minimum vertical length of M = AL + LB

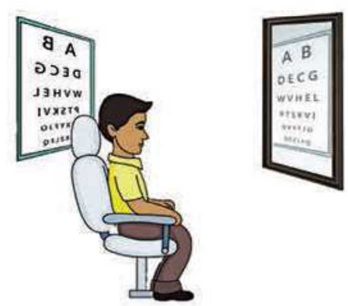
= 2 + 31 = 33 in = 2 ft 9 in

The looking glass must have a minimum vertical length of 2 ft 9 in, which is half of the height of the man.

Some Applications of Plane Mirrors

(i) Optical Testing

If the eye testing room is not large enough, the illuminated laterally inverted letters are placed behind the patient. These letters are seen correctly in the plane mirror which is in front of the patient.

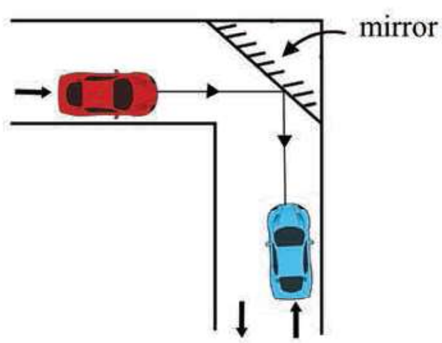


(ii) Periscope

When the view of an object is obstructed by an obstacle, the periscope can be used to see the object clearly. The periscopes in submarines use prisms instead of mirrors. In addition, periscopes are attached with telescopes to observe very distant objects.

(iii) Blind Corners

Fitting a plane mirror at a corner allows drivers to see around blind turns (The diagram is not drawn to scale).



(iv) Instrument Scales

By forming an image of the pointer, the plane mirror eliminates parallax errors in the reading of instrument scales.

Plane mirrors are also used in many optical instruments such as telescopes, overhead projectors as well as lasers. Another common use of the plane mirror is in the construction of a kaleidoscope which gives colourful multiple images of pieces of coloured glass (or) plastic.

Reviewed Exercise

1. What are differences between real and virtual images?
2. What does it mean to say that a plane mirror produce a virtual image?

Key Words : mirror, lateral inversion, real image, virtual image

8.4 REFLECTION AT CURVED MIRROR

If only a small part of the surface of a curved mirror is used for reflection, it can be considered as an outer (or) an inner surface of a hollow sphere. Only concave and convex mirrors having spherical surfaces are used in most applications. We shall now discuss the reflections at such mirrors.

(a) Concave Mirror

If the reflecting surface of a mirror forms part of the inner surface of a hollow sphere, the mirror is called a concave mirror.

(b) Convex Mirror

If the reflecting surface of a mirror forms part of the outer surface of a hollow sphere, the mirror is called a convex mirror.

(c) Pole of a Concave (or) Convex Mirror

The centre of the surface of a concave (or) convex mirror is called its pole.

(d) Centre of Curvature of a Concave (or) Convex Mirror

The centre of a sphere, part of whose surface is the concave (or) convex mirror, is called the centre of curvature of that mirror.

(The centre of curvature of a concave mirror is in front of the reflecting surface and that of a convex mirror is behind the reflecting surface.)

(e) Radius of Curvature of a Concave (or) Convex Mirror

The radius of a sphere, part of whose surface is the concave (or) convex mirror, is called the radius of curvature of that mirror.

(f) Principal Axis

The line passing through the centre of curvature and the pole of a concave (or) convex mirror is called the principal axis.

(g) Principal Focus of a Concave Mirror

When the rays parallel and close to the principal axis are incident on a concave mirror the reflected rays pass through a point on the principal axis. That point is called the principal focus of the concave mirror. Since the reflected rays actually intersect at that point, the focus of a concave mirror is a real focus.

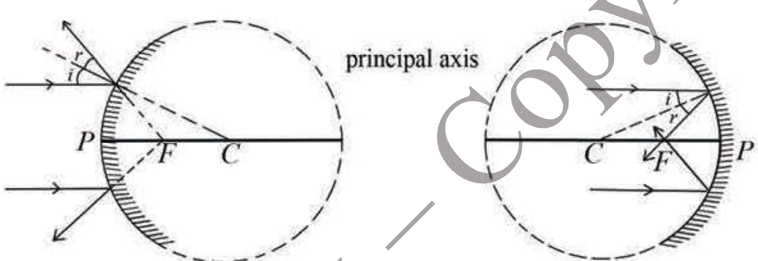
(h) Principal Focus of a Convex Mirror

When the rays parallel and close to the principal axis are incident on a convex mirror the reflected rays appear to come from a point on the principal axis. That point is called the principal focus of the convex mirror .Since the reflected rays do not actually pass through that point, the principal focus of a convex mirror is a virtual focus.

(i) Focal Length

The distance between the pole and the focus of a concave (or) convex mirror is called the focal length of the concave (or) convex mirror.

Figure 8.9 illustrates the stated definitions and the corresponding symbols.



P = pole

C = centre of curvature

F = focus

$PF = f$ = focal length

$PC = R$ = radius of curvature

Figure 8.9 Reflection at convex and concave mirrors

Relation Between Focal Length and Radius of Curvature

For rays close to the principal axis and for rays which make very small angles with the principal axis, we can show that focal length f is approximately equal to the half of the radius of curvature R, that is $f = \dfrac{R}{2}$.

Formation of Images in a Concave Mirror

The formation of images in the concave mirror for various positions of the object are shown in Figures 8.10 - 8.15.

In Figure 8.10 the object is at infinity and its image is

1. at F,
2. real,
3. inverted and
4. smaller than the object.

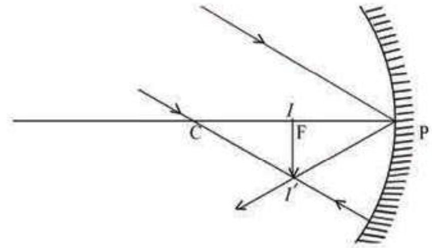


Figure 8.10 The object at infinity

In Figure 8.11 the object is beyond C and its image is

1. between C and F,
2. real,
3. inverted, and
4. smaller than the object.

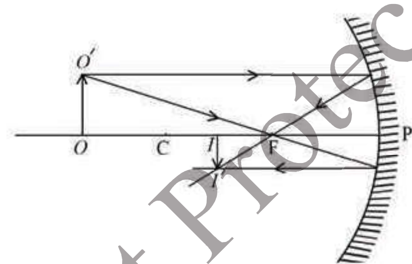


Figure 8.11 The object beyond C

In Figure 8.12 the object is at C and its image is

1. at C,
2. real,
3. inverted, and
4. of the same size as the object.

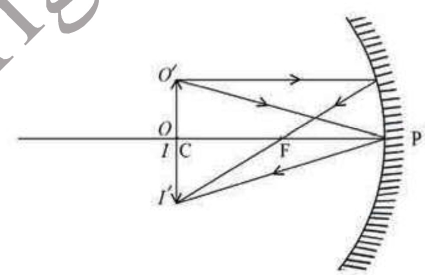


Figure 8.12 The object at C

In Figure 8.13 the object is between C and F and its image is

1. beyond C,
2. real,
3. inverted, and
4. larger than the object.

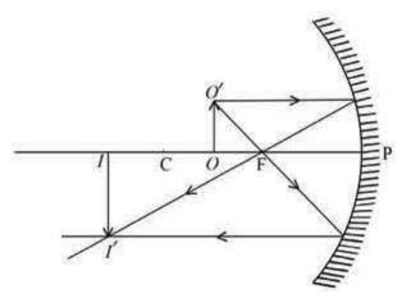


Figure 8.13 The object between C and F

In Figure 8.14 the object is at F and its image is at infinity

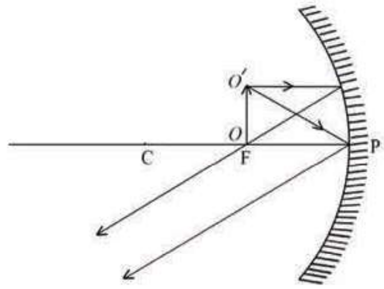


Figure 8.14 The object at F

In Figure 8.15 the object is between F and P and its image is

1. behind the mirror,
2. virtual,
3. erect, and
4. larger than the object.

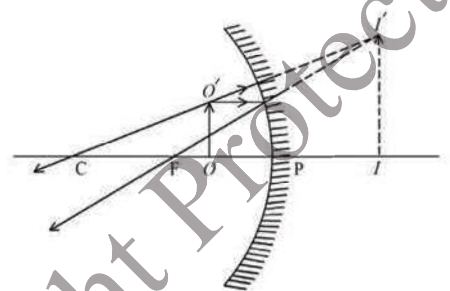


Figure 8.15 The object between F and P

Formation of Images in a Convex Mirror

The image formed in the convex mirror is always virtual, erect and smaller than the object. It is formed between P and F no matter where the object is situated (Figure 8.16).

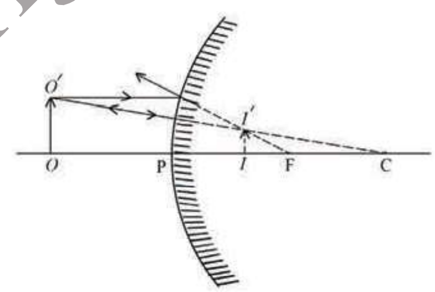


Figure 8.16 Image formed by a convex mirror

The image formed in the concave mirror can be real (or) virtual depending upon the position of the object. In addition, it may be erect (or) inverted. However the images of an object formed in plane and convex mirror are always virtual.

Some Applications of Curved Mirrors

Convex mirrors are often used as rear view mirrors of vehicles since they always give an erect image and a wide field of view. Figure 8.17 illustrates a convex mirror has a wider field of view than a plane mirror of the same size.

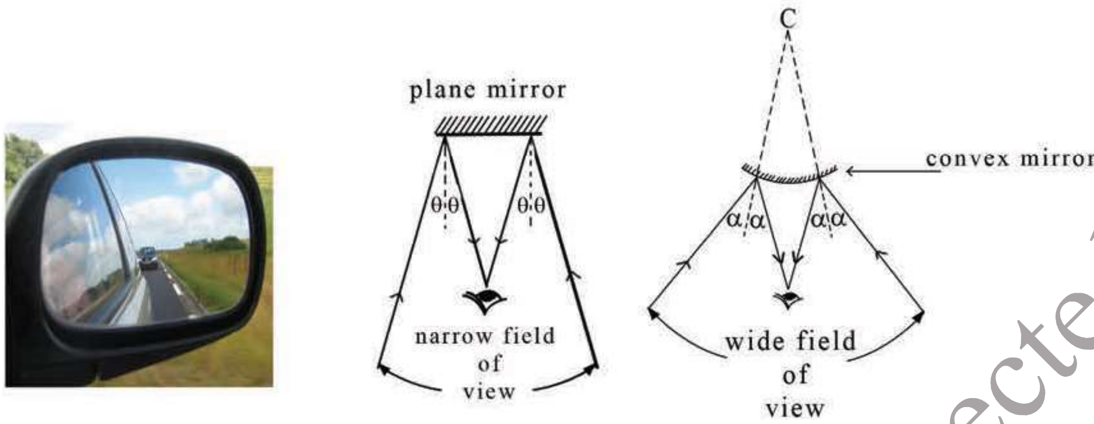


Figure 8.17 Practical use of a convex mirror and advantage of convex mirror as a rear view mirror

Concave mirrors are normally used as reflectors in motor car headlamps, torchlights and searchlights. A concave mirror may also be used as a shaving mirror since it is able to produce an enlarged image of the object shown in Figure 8.18.

Figure 8.18 Practical use of concave mirror

Sign Conventions

We have observed that the focus of a concave mirror is real and that of a convex mirror is virtual. Moreover, the images formed in these mirrors may either be real (or) virtual, and erect (or) inverted. Hence the following sign conventions are required in applying mirror formulae to solve the problems.

1. Distances of real object, real image and real focus are positive. Distances of virtual object, virtual image and virtual focus are negative.
2. The focal length and radius of curvature of a concave mirror are positive, and those of a convex mirror are negative.
3. The perpendicular distance measured above the principal axis is positive and that below the principal axis is negative.

Mirror Formula

For both concave and convex mirrors

$$\frac{1}{u}+\frac{1}{v}=\frac{1}{f} \qquad (8.1)$$

where u = object distance from the mirror
v = image distance from the mirror
f = focal length

All distances are measured from the pole of the mirror.

Magnification

The images formed by the concave and convex mirrors have various sizes depending upon the position of the object. Thus, the lateral magnification produced by a mirror is defined as the ratio of the height of the image to the height of the object.

$$\text{Magnification} = \frac{\text{height of image}}{\text{height of object}} = \frac{\text{size of image}}{\text{size of object}}$$

If m = magnification, II' = size of image and OO'= size of object

then
$$m=\frac{II'}{OO'} \qquad (8.2)$$

The magnification m can also be expressed in terms of the object distance u, and the image distance v.

$$\frac{II'}{OO'}=-\frac{v}{u} \qquad (8.3)$$

The minus sign determines both the nature and configuration of the image.

The formula for the magnification m can be expressed as $m=\dfrac{II'}{OO'}=-\dfrac{v}{u}$

Example (2) An object is placed (a) 20 cm (b) 4 cm in front of a concave mirror of focal length 12 cm. Find the nature and position of the image in each case.

(a) $u = +20$ cm

$f = +12$ cm(concave mirror)

$$\frac{1}{u}+\frac{1}{v} = \frac{1}{f}$$

$$\frac{1}{+20}+\frac{1}{v} = \frac{1}{+12}$$

$$\frac{1}{v} = \frac{1}{12}-\frac{1}{20}$$

$$v = 30 \text{ cm}$$

Since v is positive the image is real. It is formed 30 cm from the concave mirror on the same side as the object.

(b)
$$u = +4 \text{ cm}$$
$$\frac{1}{u}+\frac{1}{v} = \frac{1}{f}$$
$$\frac{1}{+4}+\frac{1}{v} = \frac{1}{+12}$$
$$\frac{1}{v} = \frac{1}{12}-\frac{1}{4}$$
$$v = -6 \text{ cm}$$
Since v is negative, the image is virtual. It is formed 6 cm behind the concave mirror.

Example (3) An object is placed 10 cm in front of a concave mirror of focal length 15 cm. Find the image position and the magnification.
$$u = +10 \text{ cm}$$
$$f = +15 \text{ cm (concave mirror)}$$
$$\frac{1}{u}+\frac{1}{v} = \frac{1}{f}$$
$$\frac{1}{+10}+\frac{1}{v} = \frac{1}{+15}$$
$$\frac{1}{v} = \frac{1}{15}-\frac{1}{10}$$
$$v = -30 \text{ cm}$$
Since v is negative, the image is virtual. It is formed 30 cm behind the concave mirror.

$$\text{Magnification} \quad m = -\frac{v}{u}$$
$$m = -\frac{(-30)}{10} = 3$$

Since $m = \frac{II'}{OO'} = 3$ or $II' = 3 \times OO'$, it can be said that the image is 3 times the size of the object and it is erect.

Example (4) The image of an object in a convex mirror is 4 cm from the mirror. If the mirror has a radius of curvature of 24 cm. Find the object position and the magnification.
The image in a convex mirror is always virtual.
$$v = -4 \text{ cm (virtual image)}$$
$$R = -24 \text{ cm (convex mirror)}$$
$$R = 2f,\ f = \frac{R}{2} = (\frac{-24}{2}) = -12 \text{ cm}$$
$$\frac{1}{u}+\frac{1}{v} = \frac{1}{f}$$
$$\frac{1}{u}+\frac{1}{-4} = \frac{1}{-12}$$

$$\frac{1}{u} = \frac{1}{-12} + \frac{1}{4}$$

$$u = 6 \text{ cm}$$

Since u is positive, the object is real. It is 6 cm from the convex mirror.

$$\text{Magnification } m = -\frac{v}{u}$$

$$m = -\frac{(-4)}{6}$$

$$m = \frac{2}{3}$$

Since $m = \frac{II'}{OO'} = \frac{2}{3}$ (or) $II' = \frac{2}{3} \times OO'$, the size of the image is $\frac{2}{3}$ times the size of the object and the image is erect.

Example (5) The image of an object in a concave mirror is erect and three times the size of the object. If the mirror has a radius of curvature of 36 cm, find the position of the object.

$$\text{Size of the image} = 3 \times \text{size of object}$$

$$II' = +3 \times OO' \quad \text{(erect image)}$$

$$\frac{II'}{OO'} = +3$$

$$m = +3$$

$$m = -\frac{v}{u}$$

$$+3 = -\frac{v}{u}$$

$$v = -3u$$

$$R = +36 \text{ cm} \quad \text{(concave mirror)}$$

$$f = \frac{R}{2} = \frac{36}{2} = 18 \text{ cm}$$

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

$$\frac{1}{u} + \frac{1}{-3u} = \frac{1}{18}$$

$$\frac{2}{3u} = \frac{1}{18}$$

$$u = 12 \text{ cm}$$

The object is placed 12 cm from the concave mirror.

SUMMARY

When light is incident on the surface of an object some of the light is sent back and this phenomenon is called **reflection of light.**

The Laws of Reflection states that

(1) The incident ray, the reflected ray and the normal all lie in the same plane.

(2) The angle of incidence is equal to the angle of reflection.

If the reflecting surface is plane, the mirror is called a **plane mirror.**

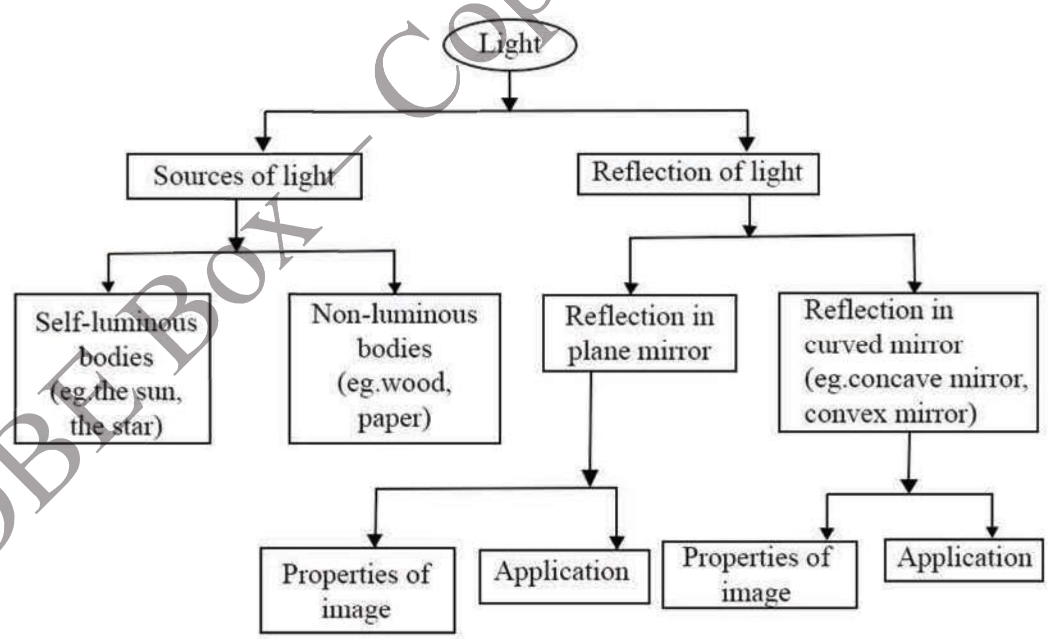
If the direction of a ray of light is reversed, the light ray will travel along its original path. This is known as **the principle of reversibility of light.**

EXERCISES

1. State the laws of reflection of light.
2. Give two examples each of objects which (a) emit their own light (b) are only visible because they reflect light from another source.
3. A man is looking into a plane mirror on the wall which is 6 ft away from him. He views the image of a chart which faces the mirror and is 2 ft behind him. Find the distance between his eyes and the image of the chart.
4. Draw a ray diagram to show that a vertical plane mirror need not be 5 ft long in order that a boy 5 ft tall may see a full-length image of himself in it.
5. In the above problem, if the boy's eyes are 4 in below the top of his head, find the height of the base of the mirror above floor level.
6. Show that a point object and its image are at equal distance from any point on the plane mirror.
7. What is meant by lateral inversion? The letter R is 5 cm in front of a plane mirror. Draw accurately the image of R in the mirror.
8. State the similarities and differences between the virtual images formed by the concave and convex mirrors.
9. When a ray parallel to the principal axis is incident on a concave mirror, it passes through the focus after reflection. By using the laws of reflection, prove that $f = \frac{R}{2}$.
10. Choose the correct answer from the following:
    A. Only a virtual image smaller than the object is formed by a concave mirror.
    B. Only a virtual image larger than the object is formed by a convex mirror.
    C. The statement given in A and B are wrong.
11. Choose the correct answer from the following:
    A. Only real images are formed by a concave mirror.
    B. Real and virtual images can be formed by a concave mirror.
    C. Real and virtual images can be formed by a convex mirror.

12. Choose the correct answer from the following:
    When an object is at the centre of curvature of a concave mirror the magnification is
    A. 0.5 B. -1.0 C. 1.5
13. A concave mirror can produce an image which is twice the size of the object. Draw a ray diagram to show this.
14. An image is 6 cm from a convex mirror which has a radius of curvature of 36 cm. Find the object position and the magnification.
15. An image one-third the size of an object is formed by a convex mirror of focal length 15 cm. How far is the object from the convex mirror?
16. An object is 20 cm in front of a concave mirror of focal length 15 cm. How far must the screen be placed from the centre of curvature of the concave mirror to receive the image of the object? If the object is 2 cm tall, find the size of the image.
17. An object is 20 cm from a mirror. If the virtual image is half the size of the object, find the radius of curvature of the mirror.
18. An object is placed 30 cm in front of a concave mirror of focal length of 10 cm. Find the image position and the magnification.

CONCEPT MAP



CHAPTER 9

ELECTRICITY

Electricity is a form of energy. There are two types of electricity: electrostatics (or) static electricity and electrodynamics (or) current electricity. Electrostatics is the study of electric charge at rest. Electrodynamics is the study of moving electric charges and their interaction with magnetic and electric fields. In this chapter, charges at rest (electrostatic charges) and electrification are studied.

Learning Outcomes

It is expected that students will

- investigate electric charges.
- distinguish the repulsive and attractive force between two charges.
- discuss that a charged body has electron deficiency (or) excess.
- identify the characteristics of conductors, insulators and semiconductors.
- explain the process of charging by induction.
- demonstrate an understanding of electrification and nature of electrostatic force.
- apply basic knowledge of electrostatics to daily-life uses.

Electric charge (or) electricity, can be provided by batteries and generators. But some materials become charged when they are rubbed. These charges are electrostatic charge or static electricity.

The two kinds of static electric charge are positive charge and negative charge. The uses of static electricity are electrostatic precipitators, inkjet printers and photocopiers. Another example of static electricity is lightning discharge.

Electrical energy can be transformed into other forms of energy, such as heat energy, mechanical energy, light energy and sound energy. It is used in domestic electric appliances, in industries, transportation and communication works. In technologically advanced countries scientists are trying to generate considerable amount of electrical energy from the wind, from the sea and from the sun.

9.1 ELECTRIC CHARGES AND ELECTRIC FORCES

Electric charge is the physical property of matter that causes an electric force when placed in an electromagnetic field. Electric charges may be either at rest (static charges) (or) in motion (moving charges). Flow of charges is called an electric current.

[https://en.m.wikipedia.org/wiki/Benjamin_Franklin] **Benjamin Franklin (1706-1790)**

A French scientist, Du Fay, studied the nature of electric charges possessed by substances and found that there were only two kinds of charges. Benjamin Franklin named them positive charge which is represented by a plus sign (+) and negative charge by a minus sign (−). Like charges repel and unlike charges attract. The closer the charges are, the greater the force between them. When two charged objects are brought together, they produce either attractive (or) repulsive force (Figure 9.1).

The electric force between two charged objects is one of the fundamental forces of nature. The electric force holds the particles that make up an atom together. Charged objects can exert forces to other charged objects without being in contact with them. This is possible because there is an electric field around each charge.

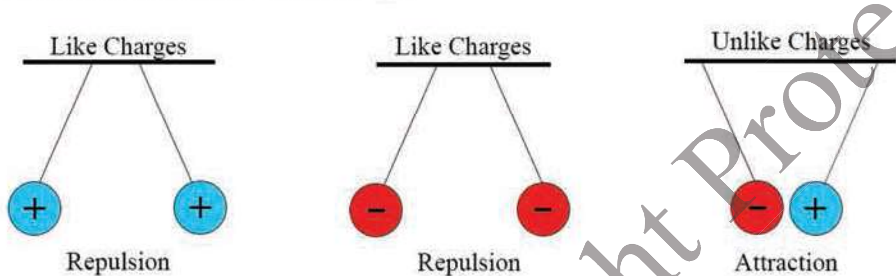


Figure 9.1 Repulsion and attraction between like and unlike charges

Unit of charge

In SI units, electric charge is measured in coulomb (C), in honour of Charles Augustin de Coulomb, a French physicist. He discovered that the force between two charged objects depends on the magnitude of their charges and on how far apart they are. Since the magnitude of charge of an electron is 1.6×10^{-19} C, one coulomb of charge is equivalent to the charge of 6.25×10^{18} electrons. One coulomb is a relatively large value of charge.

Charles de Coulomb, Physicist, Scientist (1736–1806)

[https://www.biography.com/scientist/charles.de-coulomb]

1 microcoulomb (1 μC) = 10^{-6} C (one millionth of a coulomb)

Charge is one of the quantized physical quantities. It means that charge cannot take any arbitrary values, but only discrete values that are integral multiples of the fundamental charge that is charge of an electron.
$Q = n\,e$, where Q = electric charge, n = integer, e = charge of an electron = 1.6×10^{-19} C

Reviewed Exercise

- When two bodies attract each other electrically, must both of them be charged?

Key Words: positive charge, negative charge, repulsive force, attractive force, quantized

9.2 MATTER AND ELECTRICITY

Matter is composed of atoms which are very small in size. An atom consists of core called the nucleus around which the particles called electrons are moving in orbits.

An electron is a negatively charged particle having a charge of -1.6×10^{-19} C. The nucleus consists of two kinds of particles called proton and neutron. A proton is a positively charged particle and a neutron is an uncharged particle. An electron and a proton have the same magnitude of electric charge. The nucleus has net positive charge. The magnitude of positive charge of the nucleus is equal to the sum of the positive charges of all the protons present in the nucleus.

In a normal atom the number of orbiting electrons is always equal to the number of protons. Since the magnitude of positive charge of the nucleus is equal to that of the total negative charge of electrons, a normal atom has no net charge. It is said to be electrically neutral.

If an atom gains one (or) more electrons, it carries a negative charge. If an atom loses one (or) more electrons, it becomes positively charged. When an atom becomes a charged atom, it is called an ion.

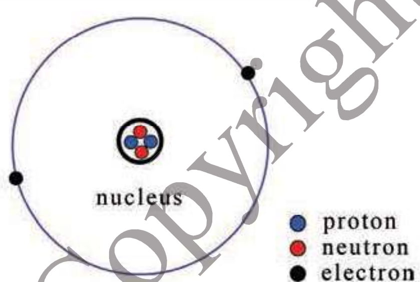


Figure 9.2 A neutral atom (helium) has the same number of electrons and protons

Reviewed Exercise

- Why does a nucleus possess the positive charge?

Key Words: atom, proton, electron, neutron

9.3 CONDUCTORS, INSULATORS AND SEMICONDUCTORS

As already mentioned, in an atom the negatively charged electrons are moving around a positively charged nucleus. Some of these electrons are near the nucleus while other electrons are further away from the nucleus. Since positive and negative charges attract each other, electrons experience an attractive force of the nucleus. As the attractive force is greater for the electrons closer to the nucleus so these electrons cannot move freely. This means that the inner electrons are tightly bound by the nucleus. The electrons closer to the nucleus are called bound electrons.

The electrons far away from the nucleus (or) the outer electrons experience less attractive force of the nucleus. This means that the outer electrons are loosely bound and are called free electrons. They can move from one atom to another.

The number of free electrons in a substance depends upon the nature of that substance. The substance which has plenty of free electrons is called a conductor and the substance which has very few (or) no free electrons is called an insulator.

Metals are good electrical conductors. Some of their electrons are so loosely held to their atoms that they can pass freely from atom to atom. These free electrons make metals good conductors. Most non-metals conduct electricity poorly (or) not at all, although carbon is an exception.

In insulators all the electrons are held tightly in position and unable to move from atom to atom. Insulators are materials that hardly conduct electricity. Although the electrons are not free to move in insulators, they can be transferred from one object to another.

Some substances which contain a moderate amount of free electrons are called semiconductors. Such substances are neither conductors nor insulators. Silicon and germanium are widely used as semiconductors.

Metals such as gold, silver, copper, brass, aluminium etc., are good conductors.
Non-metals such as plastic, glass, rubber, wax, quartz, etc., are insulators.
Transistors and other electronic components are made from semiconductors.

Reviewed Exercise

1. What do you understand by a bound electron and a free electron?
2. Is your body a conductor (or) an insulator? Mention five insulators and five conductors.
3. There are very large numbers of charged particles in most objects. Why then, don't most objects exhibit static electricity?

Key Words: bound electrons, free electrons, conductor, insulator, semiconductor

9.4 ELECTRIFICATION

(1) Electrification by Rubbing

Normally, atoms have equal numbers of electrons and protons so the net (overall) charge on a material is zero. However, when the two insulating materials are rubbed together, electrons may be transferred from one to the other. If two uncharged objects are rubbed with one another both of them become charged. This is also called charging by friction.

It is important that the rubbing does not produce (or) create charge. It simply removes the electrons from one object and transfers them to the other. As shown in Figure 9.3 when a glass rod is rubbed with a silk cloth, the glass rod becomes positively charged while the silk cloth is negatively charged. This is because some electrons of the glass rod are transferred to the silk cloth. Hence, the glass rod loses electrons while the silk cloth gains electrons.

As another example, when a plastic rod is rubbed with fur, the plastic rod possesses a negative charge while the fur becomes positively charged.

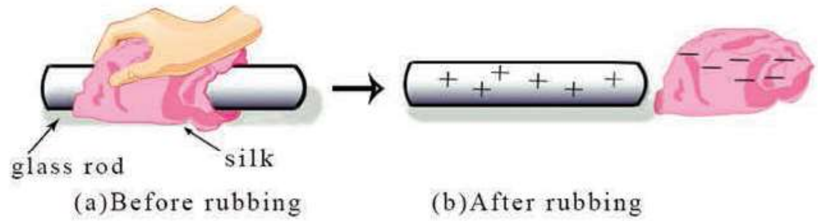
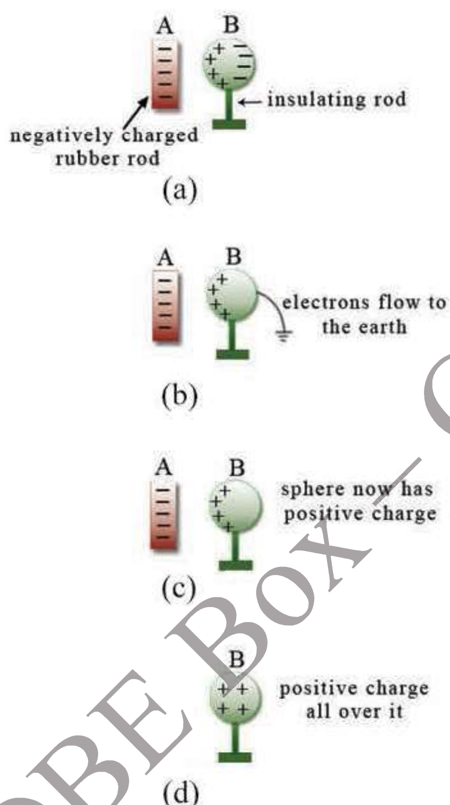


Figure 9.3 A glass rod is rubbed with a silk cloth

(2) Electrification by Induction

(i) Charging a single metal conductor by induction

Induction is the process of charging a conductor without any contact with the charged body. A charged object can attract uncharged objects. We start with two objects: an object A (negatively charged rod) and an uncharged metal sphere B on an insulating stand. The method is as follows.



Step 1

Object A is a negatively charged rod. When the metal sphere B is placed near it, like charges repel so electrons in the sphere move to right side of the sphere.

Step 2

Now the sphere is touched, by hand (or) by a wire connected to earth. Electrons flow from the sphere to the earth through the wire.

Step 3

The connection is removed. Now the sphere becomes a positively charged object.

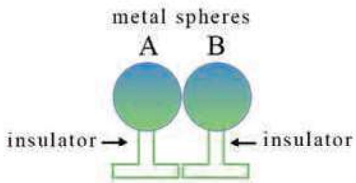
Step 4

Finally, the object A is taken away from sphere B, positive charges are uniformly distributed on the surface of the sphere.

Figure 9.4 Four steps in charging a single metal sphere by induction

(ii) **Charging two metal spheres by induction**

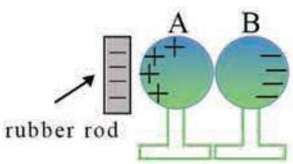
The method of charging a two-metal sphere system by induction using a negatively charged rubber rod is as follows:



(a)

Step 1

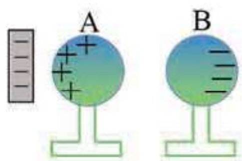
Two metal spheres of the same size A and B supported on insulating stands are in contact. These spheres can be considered as a single conductor. They are uncharged spheres.



(b)

Step 2

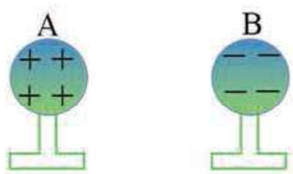
A negatively charged rubber rod is brought near (not touching) the sphere A. Since like charges repel the free electrons in both spheres move away from the rod and they collect at the right surface of sphere B. Now sphere A has excess positive charges, while sphere B has excess negative charges. These excess charges on the surfaces of A and B are called induced charges.



(c)

Step 3

Keeping the rubber rod in position, sphere B moves slightly from sphere A. The two spheres have opposite charges.



(d)

Step 4

Then the rubber rod is removed. Sphere A becomes a positively charged sphere and sphere B becomes a negatively charged sphere. Sphere A and B now have an equal number of opposite charges, the magnitude of the charge on the rubber rod remains unchanged.

Figure 9.5 Four steps in charging two metal spheres by induction

The law of conservation of electric charge is one of the fundamental laws. That is 'The net electric charge in an isolated system remains constant'. The net charge is the algebraic sum of the charges in an isolated system.

For example, in the experiment on electrification by stroking the glass rod with a silk cloth, they together form an isolated system. There is no charge transfer between the surrounding and the isolated system. The net charge of isolated system remains constant before and after stroking.

Reviewed Exercise

- If the balloon near a wall is charged by rubbing with hair, the charged balloon will stick to a wall. Explain this phenomenon.

Key Words: electrification, induction

Some Applications of Static Electric Charges

There are several practical uses of static electricity in our daily life. Photocopier, electrostatic paint spraying, electrostatic precipitator etc., are based on static electric charges.

Photocopier

Basic operation of a photocopier is the attraction of charged toner (ink) to the region on the selenium coated drum that is oppositely charged.

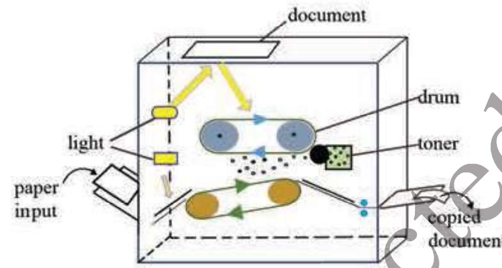


Figure 9.6 Static electricity used in a photocopier

Electrostatic paint spraying

The item (e.g., metal car frame) to be painted receives the negative charge from a negatively charged electrode. The droplets of paint emerge from the spray gun are positively charged. As the droplets all carry the same charge they repel and spread out forming a fine spray. The paint droplets are attracted to the surface of the frame. The paint is attracted statically to metal frame from every direction so there is no waste of spray paint.

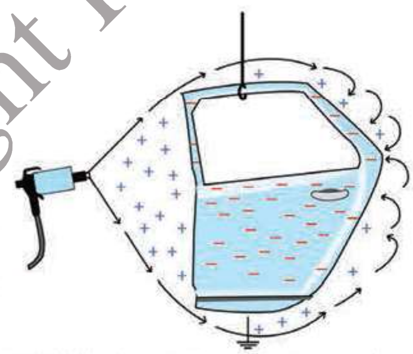


Figure 9.7 Electrostatic paint spraying

Electrostatic precipitator

The waste smoke, dust and fly ash are passed through a negatively charged mesh of wire in the chimney and the fly ash particles become negatively charged. Higher up the chimney these charged particles are attracted and stick to positively charged metal plate. The clean smoke is then released into the atmosphere.

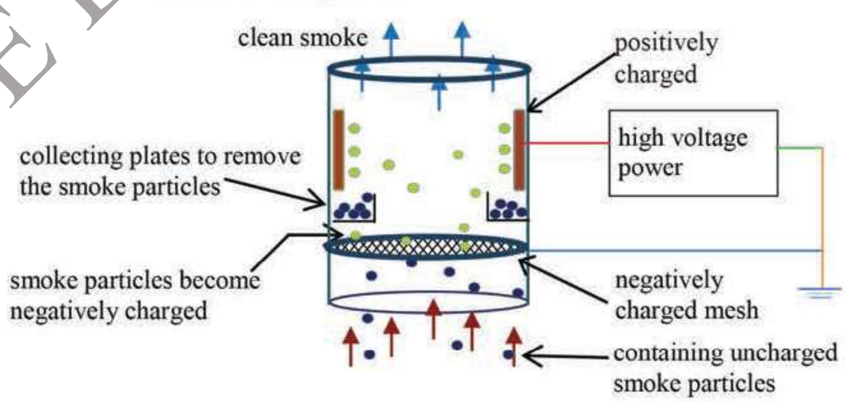


Figure 9.8 Electrostatic precipitator

Disadvantages of Static Electricity

In a scientific perspective, static electricity occurs when there is an imbalance of charges between two objects. Static electricity can build up as a result of collisions among the molecules in clouds. This can cause a huge spark to form between the ground and the cloud. This causes a lightning discharge, therefore, a flow of charge through the atmosphere.

As aircraft fly through the air, they can become charged with static electricity. A build-up of static charge is a potential danger when refuelling aircraft (or) vehicles. Fuel running through the pipes can provide the friction needed to create a static charge. To prevent this, aircraft are earthed with a conductor during refuelling.

Fuel tankers (bowsers) that transport fuel on roads must be earthed before any fuel is transferred, to prevent sparks causing a fire (or) explosion.Television screen and computer monitors become charged with static electricity when they are powered. These charges attract dust.

SUMMARY

Electrostatics is the study of electric charges at rest .
The two kinds of static electric charge are positive charge and negative charge.
Like charges repel and unlike charges attract.
The electric force between two charged objects is one of the fundamental forces of nature.
Charge is measured in coulomb (C).
The inner electrons that are tightly bound by nucleus are called **bound electrons**.
The electrons far away from the nucleus (or) the outer electrons are loosely bound and are called **free electrons**.
The substance which has plenty of free electrons is called a **conductor**.
The substance which has very few (or) no free electrons is called an **insulator.**
Some substances which contain a moderate amount of free electrons are called **semiconductors.**

EXERCISES

1. When a negatively charged sphere is brought near a suspended body, the suspended body is attracted to it. Is it correct to assume that the body is positively charged?
2. Choose the correct answer from the following.
   A. When an object contains an excess of electrons it has a positive charge.
   B. When an object contains a deficiency of electrons it has a positive electric charge.
   C. Since the nuclei of the atoms in an object are positively charged it has a positive electric charge.
   D. When the electrons of the atoms in an object are positively charged it has a positive electric charge.

3. Choose the correct answer from the following:

(i) The charge carrier of the conductor are _______.
(A. protons B. neutrons C. electrons)

(ii) _________ is a conductor.
(A. Wood B. Plastic C. Metal)

(iii) The SI unit of the electric charge is _________.
(A. coulomb B. ampere C. watt)

(iv) When an electron is removed from an atom, it becomes _______ ion.
(A. positive B. negative C. none of them)

(v) There is an electric current in conductor when electrons are _______.
(A. moving B. at rest C. none of them)

(vi) The magnitude of the charge of an electron is 1.6×10^{-19} C. A total of 10^4 electrons have been removed from an uncharged pith ball. Its charge now is _______.
(A. $+1.6 \times 10^{-15}$ C , B. $+1.6 \times 10^{-23}$ C , C. -1.6×10^{-15} C)

(vii) A glass rod becomes positively charged when it is rubbed with silk. The glass rod becomes charged because it _______ .
(A. gains protons, B. gains electrons, C. loses electrons)

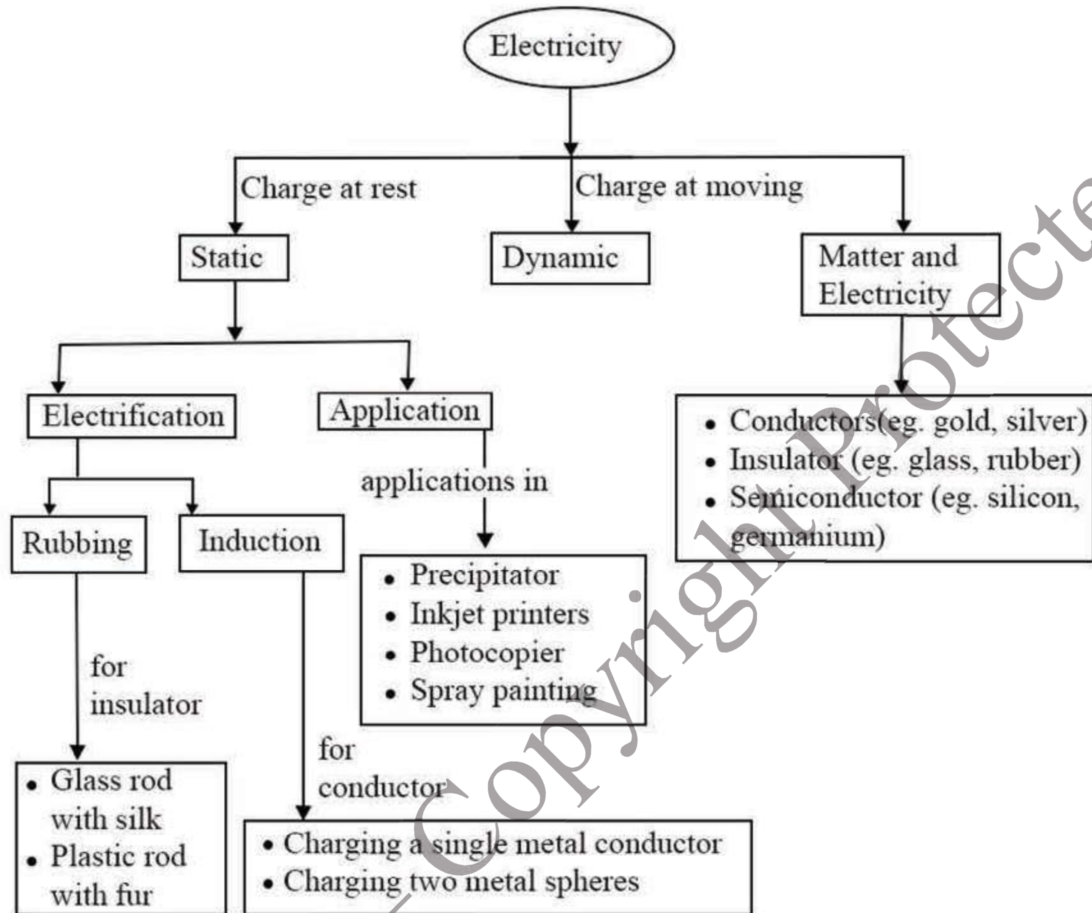
4. Match the following:

(i) Electron	A. positive charge
(ii) Proton	B. repel
(iii) Like charges	C. attract
(iv) Unlike charges	D. negative charge

5. Common static electricity involves charges ranging from nanocoulombs to microcoulombs. (a) How many electrons are needed to form a charge of – 2 nC? (b) How many electrons must be removed from a neutral object to have a net charge of +1 μC?

6. To start a car engine, the car battery moves 3.75×10^{20} electrons through the starter motor in one second. How many coulombs of charge were moved in that time?

CONCEPT MAP


Electricity
Charge at rest
Charge at moving
Static
Dynamic
Matter and Electricity
Electrification
Application
applications in
Rubbing
Induction
Precipitator
Inkjet printers
Photocopier
Spray painting
Conductors(eg. gold, silver)
Insulator (eg. glass, rubber)
Semiconductor (eg. silicon, germanium)
for insulator
for conductor
Glass rod with silk
Plastic rod with fur
Charging a single metal conductor
Charging two metal spheres

CHAPTER 10

MAGNETISM

Magnetism is a phenomenon associated with magnetic field. A magnet has a magnetic field around it. A magnetic force arises due to interaction of magnetic fields.

Learning Outcomes

It is expected that students will

- analyse that the attraction between a specimen and a magnet is not sufficient enough to confirm that the specimen is a magnet.
- determine that all magnetised and unmagnetised materials consist of very tiny magnets.
- define a magnetic field in which magnetic effect can be detected and illustrate the pattern of magnetic field.
- differentiate the magnetic properties of iron and steel.
- demonstrate basic knowledge of magnets and their applications.

10.1 MAGNETS AND MAGNETIC MATERIALS

Magnets are the material which exhibit magnetic properties such as (1) attract magnetic materials (2) have two poles and (3) like poles repel, unlike poles attract.

Magnetic and Non-Magnetic Materials

Magnetite consists of an oxide of iron. This natural magnet attracts certain materials such as cobalt, nickel and some alloys such as steel. These materials are called magnetic materials. Materials such as brass, copper, wood and plastics that are not attracted by a magnet are called non-magnetic materials.

Any materials (such as magnetite) that is able to keep its magnetism for a long time is called a permanent magnet. Modern-day permanent magnets are usually made of steel (an alloy of iron) and special alloys such as alcomax and alnico which contain metals such as iron, nickel, copper, cobalt and aluminium. Another type of permanent magnet is ceramic magnet which is made from powders called ferrites (compounds of iron oxide with other metal oxides). However, these ceramic magnets are brittle.

Properties of Magnets

Besides exhibiting the property of attracting magnetic materials, all magnets also exhibit the following properties:

Magnetic Poles

Figure 10.1 shows what happens when we sprinkle some steel pins onto a magnet. Most of the pins are attracted to the two ends of the magnet.These two ends are called poles of the magnet.

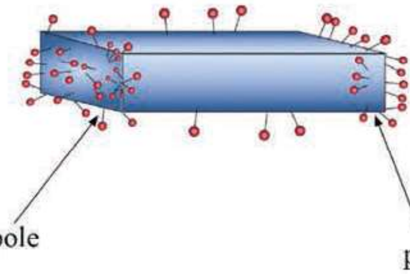


Figure 10.1 The pins show the positions of the poles of the magnet

North and South Poles

In Figure 10.2, the suspended bar magnet oscillates freely in air. When the suspended bar magnet comes to rest, one end always points towards the northern end of the Earth. This end of the magnet is thus called the north-seeking pole. Similarly, the other end of the magnet is called the south-seeking pole.

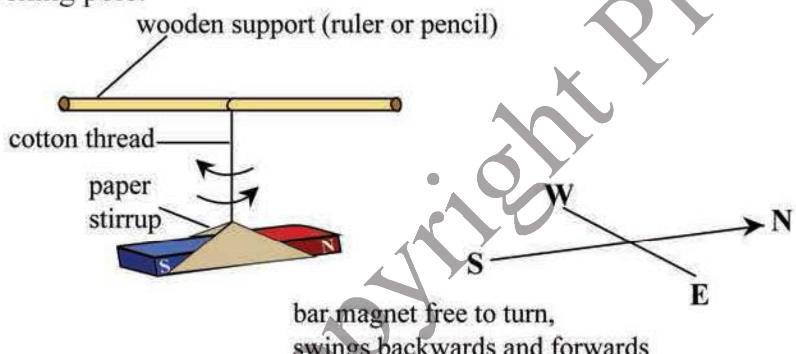


Figure 10.2 A suspended magnet always points north and south

The north-seeking pole and south-seeking pole of the magnet are usually referred to as simply the north pole (N-pole) and the south pole (S-pole) of the magnet.

Law of magnetic poles : Like poles repel and unlike poles attract.

A magnet can be used as a compass for navigation.

Magnetic Pole Strength and Magnetic Force

Magnetic pole strength is a measure of the strength of magnetic poles. When two magnetic poles are brought close to each other, one pole exerts certain force, either attractive (or) repulsive, on the other magnetic pole.

The force between two poles is directly propotional to the product of the pole strengths and inversely proportional to the distance squared between them.

Reviewed Exercise

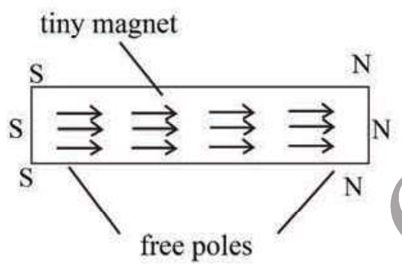
- Give examples of magnetic materials and non-magnetic materials.

Key Words : magnet, pole, alloy, strength

10.2 THEORY OF MAGNETISM

Figure 10.3 Each piece of the magnetised steel bar is a magnet

When we take a thin piece of magnetised steel bar and cut it into three smaller pieces. We will notice that every piece is a magnet with a N-pole and S-pole. Therefore, it would be reasonable to imagine that if we keep on cutting each piece of the magnet into even smaller pieces, they would still be magnetised (Figure 10.3). In other words, we can suppose that the original magnet is made up of lots of magnets all lined up with their N-poles pointing in same direction. This explains why the poles of the magnet are around the ends as shown in Figure 10.4 which illustrates a magnetised bar composed of tiny magnets. In the case of unmagnetised bar, we can imagine the 'tiny' magnets pointing in random direction as shown in Figure 10.5. The resulting magnetic effect of all the tiny magnets is then cancelled out and thus the bar is said to be unmagnetised.



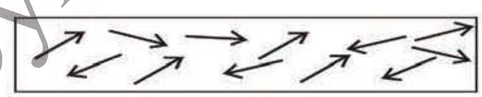


Figure 10.4 A magnetised bar

Figure 10.5 An unmagnetised bar

> Both the magnetised materials (inclusive of magnets) and unmagnetised materials are made up of tiny magnets.

Key Words : magnetised, unmagnetised

10.3 MAGNETIC FIELDS

The magnetic field is a region where magnetic effects can be detected. Distribution of magnetic field can be visualized by the magnetic lines of force. The magnetic lines of force leave north pole and enter south pole. To show the pattern of a magnetic field around a bar magnet, we can sprinkle iron filings lightly on a paper, with a bar magnet underneath, and tapping the paper gently. Figure 10.6 shows the iron filings falling into a certain pattern which is the magnetic field pattern.

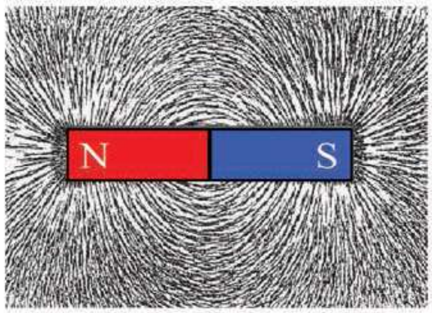
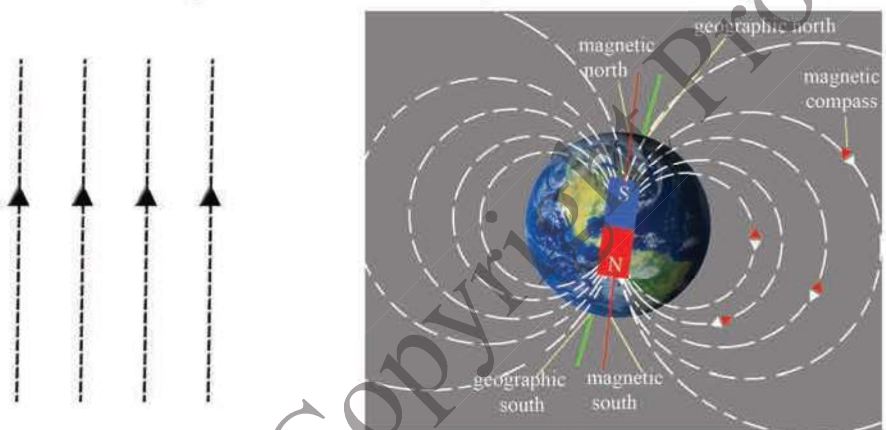


Figure 10.6 The magnetic field pattern of a bar magnet

The Earth's Magnetic Field

The Earth has a magnetic field. In other words, we can think of the Earth as having an imaginary bar magnet inside it with magnetic north and south poles as shown in Figure 10.7.



(a) (b)

Figure 10.7 (a) The Earth's magnetic field at any particular location can be considered as uniform (b) The Earth's magnetic field

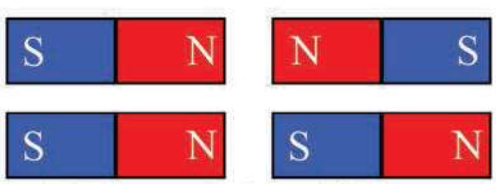
The magnetic north lies somewhere in the sea in northern Canada but has been shifting slowly over the years. Magnetic fields can also be found in the interior of atoms and in stars and other celestial bodies.

> A magnetic field has neither a starting point nor an end point because magnets never have a monopole in contrast to a point electric charge.

Reviewed Exercise

1. Describe an experiment to determine the positions of the poles of a bar magnet.
2. What experiment would you conduct to show the magnetic lines around a magnet?
3. Sketch on Figures, the magnetic field patterns formed between each pair of poles of the magnets.

(a) (b)



Key Words : magnetc field, magnetic lines of force

10.4 MAGNETISATION AND INDUCED MAGNETISM

A process of making a magnetic material into a magnet is called magnetisation. Two types of magnetisation are (i) magnetisation by stroking and (ii) magnetisation using direct current.

Magnetisation by Stroking

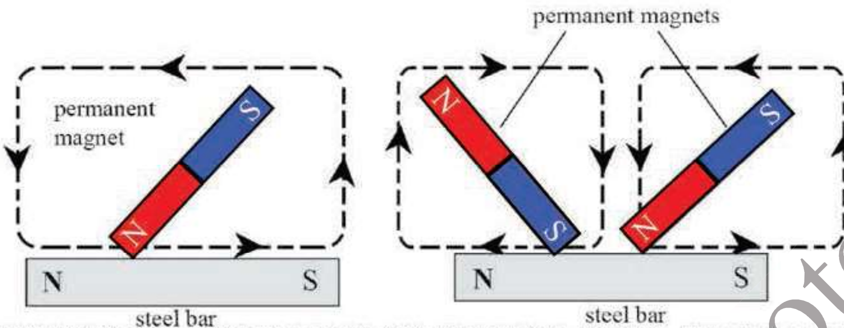


Figure 10.8 Magnetising a steel bar using one permanent magnet and two permanent magnets respectively

Figure 10.8 shows how to magnetise a steel bar using one permanent magnet and two permanent magnets respectively. The bar is stroked several times in the same direction along its length. The magnet (or) magnets must be lifted high above the bar between successive strokes. The end of the steel bar where the strokes finish always has the opposite polarity to that of the end of the stroking magnet in contact with it.

Magnetisation using Direct Current

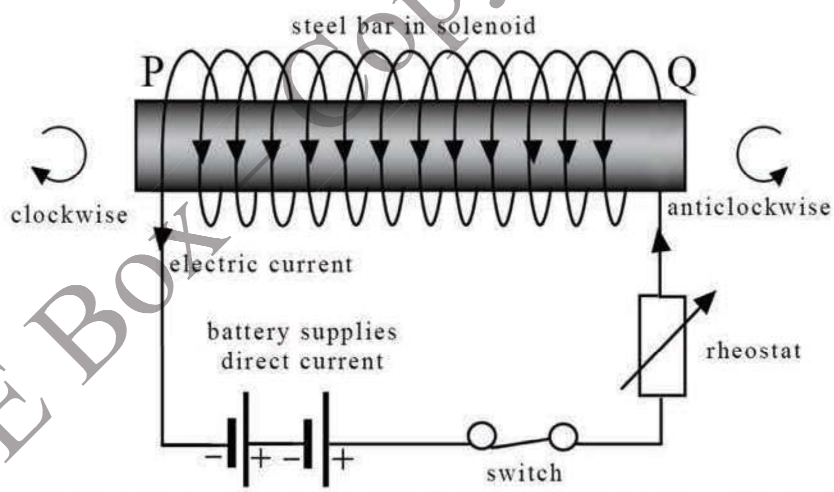


Figure 10.9 Magnetisation by the electrical method using direct current

The best way to make powerful magnets is to use the magnetic effect of an electric current. A steel bar is placed inside a solenoid and a direct current is passed through the solenoid. The solenoid produces a magnetic field that magnetises the steel bar permanently (permanent magnet). When the current through the solenoid is switched off, the steel bar stays magnetised. If an iron bar is placed instead of steel bar, the iron bar becomes magnetised temporarily (electromagnet). The polarities of the magnet produced depend on the direction of electric current.

Induced Magnetism

When a piece of unmagnetised magnetic material (such as iron or steel) is brought near to the pole of a permanent magnet, it is attracted to the magnet and becomes a magnet itself. This is called induced magnetism. The material is said to have magnetism induced in it. Figure 10.10 shows induced magnet being formed when a permanent magnet is brought near to a soft-iron bar.

Figure10.10 Permanent magnet brought near to soft-iron bar and soft-iron bar becomes an induced magnet

In Figure10.10 the north pole of the permanent magnet induces an S-pole in the near end of the soft iron while the far end of the soft iron becomes an N-pole. To check that the far end of the soft iron is a North-pole, hang two iron clips from the far end of the induced magnet as shown in Figure 10.11.

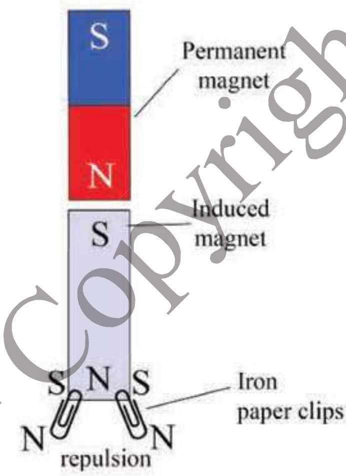
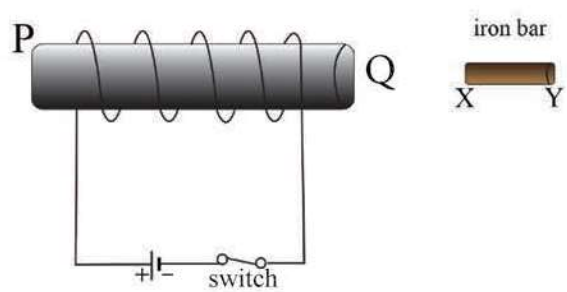


Figure10.11 The two iron clips become induced magnets and show repulsion between the far ends

Reviewed Exercise

- As shown in Figure when the switch is closed, which of the following pairs of poles is correct?

A. P is north and X is south.
B. P is south and X is south.
C. P is north and X is north.
D. P is south and X is north.



Key Words : stroking, electromagnet, permanent magnet

10.5 MAGNETIC PROPERTIES OF IRON AND STEEL

Iron is an element while steel is an alloy comprised of iron and carbon. Magnetic materials such as steel which are harder to magnetise but retain their magnetism longer are called hard magnetic materials. Magnetic materials such as iron or special alloys like mumetal alloy which are easier to magnetise but do not retain their magnetism very long are called soft magnetic materials.

The comparison of magnetic properties between iron and steel

The magnetic properties of iron	The magnetic properties of steel
- can be easily magnetised and demagnetised	- is hard to magnetise and demagnetise than iron
- can be magnetised by a weak magnetic field	- requires a strong magnetic field to magnetise.
- retains its magnetism temporarily	- retains its magnetism permanently

Both types of magnetic materials have their own useful applications. For example, the hard magnetic materials such as steel are used in the making of permanent magnets, bar magnet, electric metre and loudspeaker. Soft magnetic materials (such as iron) are used in the cores of transformers, electromagnets, magnetic shielding, electric bell and magnetic relays.

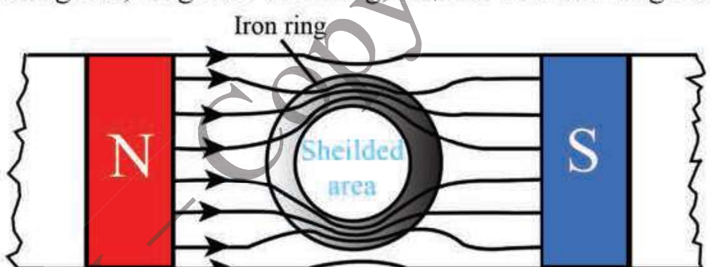
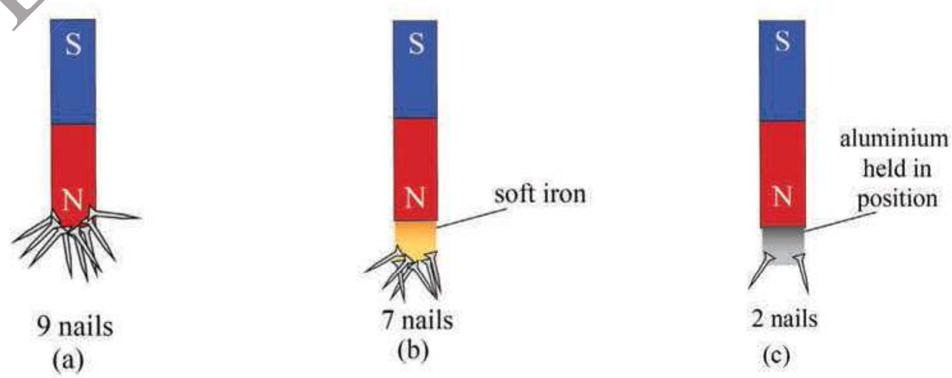


Figure. 10.12 Magnetic shielding to store magnetically sensitive instruments such as watches

Reviewed Exercise

- Experiments were conducted to test the ability of a vertically held bar magnet to attract soft iron nails. The results are shown in Figure (a, b and c).



(i) What happened to the soft iron nails when they were placed in contact with the magnet?
(ii) Suggest why the soft iron in Figure (b) picked up almost as many nails as the magnet alone.
(iii) State and explain what would happened if the magnet was gently removed whilst the soft iron is still holding the 7 nails.
(iv) Although aluminium is a non-magnetic material, a few nails were attracted to it when it was placed at the end of the magnet suggest the reason for this.

Key Words : hard magnetic material, soft magnetic material, magnetic shield

SUMMARY

Magnets are the material which exhibit magnetic properties such as (1) attract magnetic materials (2) have two poles and (3) like poles repel, unlike poles attract.

Magnetite consists of an oxide of iron. This natural magnet attracts certain materials such as cobalt, nickel and some alloys such as steel. These materials are called **magnetic materials.** Materials such as brass, copper, wood and plastics that are not attracted by a magnet are called **non-magnetic materials.**

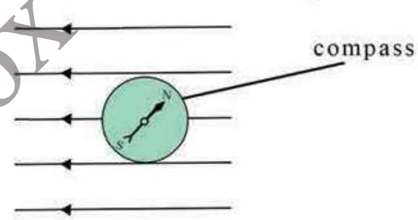
The magnetic field is a region where magnetic effects can be detected.

A process of making a magnetic material into a magnet is called **magnetisation.**

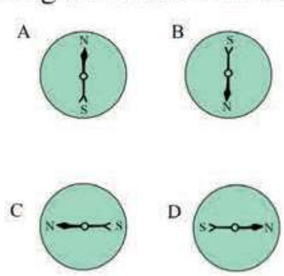
EXERCISES

1. It can be confirmed that a metal bar is already magnetised if
   A. a magnet is attracted to it.
   B. an aluminium bar is attracted to it.
   C. both ends of a compass needle are attracted to the same end of the bar.
   D. one end of a compass needle is repelled by one end of the bar.

2. A small compass is placed in the uniform magnetic field as shown in Figure.



To which of the following directions will the compass needle point finally?



3. A metal bar PQ hung by a thin thread always comes to rest with end Q pointing North. Another bar XY of the same metal settles in no definite direction. Which of the following is true?
   A. End Q attracts end X but repels end Y.
   B. End Q repels end X but attracts end Y.
   C. End Q attracts both end X and end Y.
   D. End Q neither attracts nor repels end X and end Y.

4. Figure shows a strong magnet holding three paperclips. If a weaker magnet brought close to the end of the last clip as shown it will

   A. bend away from the magnet.
   B. bend towards the magnet.
   C. fall to the ground.
   D. stay still.

5. Which one of the following materials is most suitable for the core of an electromagnet?
   A. Steel C. Iron
   B. Brass D. Aluminium

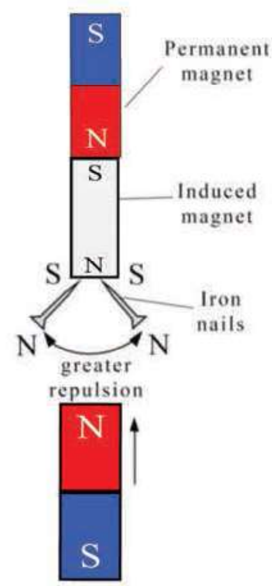
6. Which of the following materials is correctly described?

material	property	use
A. iron	not easily demagnetised	permanent magnet
B. iron	easily demagnetised	electro-magnet
C. steel	not easily demagnetised	electro-magnet
D. steel	easily demagnetised	permanent magnet

7. In which device is a permanent magnet used?
   A. An electric bell C. A plotting compass
   B. An electromagnet D. A relay

8. (a) Explain why a greater repulsion is occurred when a N-pole of bar magnet is brought towards the two far ends of the two iron nails for the given figure.

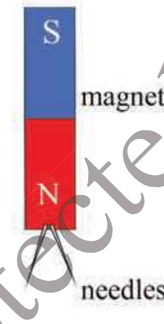
   (b) Suggest what would be observed when a S-pole of another bar magnet is brought towards the two far ends of the two iron-nails in Figure. Explain by an appropriate Figure.



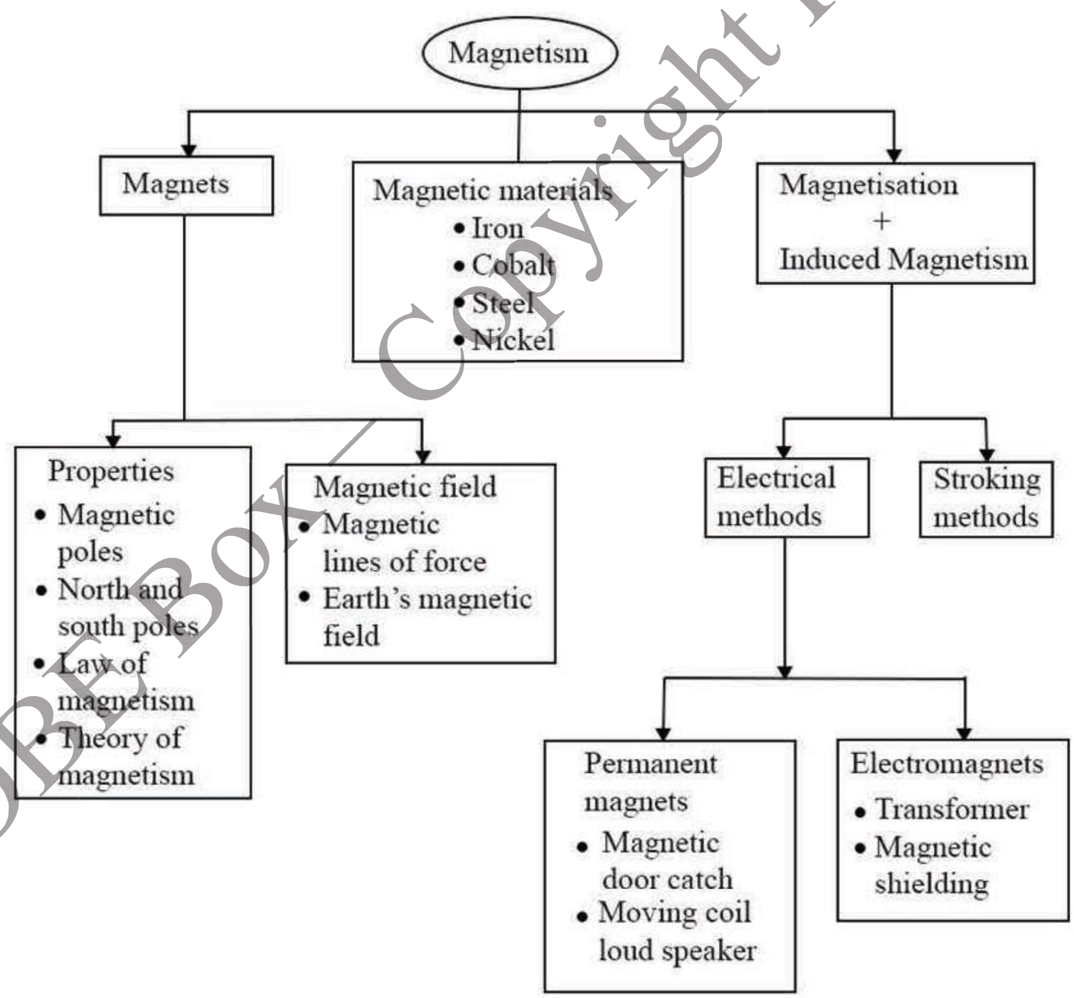
9. What are the main differences in the magnetic properties of soft iron and steel? How would you demonstrate them, experimentally? For each substance, name an instrument (or) piece of apparatus in which it is used because of its magnetic properties.

10. Describe briefly, with the help of simple diagrams if necessary,
    (a) how you would magnetise a steel rod PQ using a bar magnet so that P is a S-pole;
    (b) how an electric current can be used to make P a S-pole;
    (c) how you would check that the end P was a S pole after operations (a) and (b);
    (d) an electrical method to demagnetise PQ.

11. Give brief explanations of the following:
    (a) A piece of soft iron is attracted by a magnet.
    (b) A small bar magnet placed on top of a cork floating on water, does not move towards the north.
    (c) Two steel needles hanging from the lower end of a vertical bar magnet do not hang vertically in Figure.



CONCEPT MAP



CHAPTER 11

QUANTUM AND ATOMIC PHYSICS

All theories of physics developed before the arrival of relativity and quantum mechanics and any work derived from them are called classical physics. On the other hand, the theories derived from the basic principles of relativity and quantum mechanics which are two pillars of physics today, are called modern physics. The word modern was chosen since the main foundations of the two pillars of physics were laid in the first three decades of the twentieth century.

Learning Outcomes

It is expected that students will

- explain thermionic emission.
- describe the structure of a vacuum diode to visualize the flow of electrons from the filament to the plate.
- discuss blackbody radiation and quantum concept for microscopic particles.
- identify and explain some physical phenomena which could not be explained by classical Physics.
- describe the size of an atom and simplified models of atom.
- recognize the origin and evolution of the visible universe such as distance scales and sizes of astrophysical objects used in astrophysics.
- develop the competence in reasoning, comprehension and analysis of modern concepts of physics.

11.1 THERMIONIC EMISSION AND VACUUM DIODE

Thermionic Emission

The process by which, free electrons are emitted from the surface of a metal when external heat energy is applied, is called thermionic emission. Thermionic emission occurs in metals that are heated to a very high temperature. In other words, thermionic emission occurs, when a large amount of external energy in the form of heat is supplied to the free electrons in the metals.

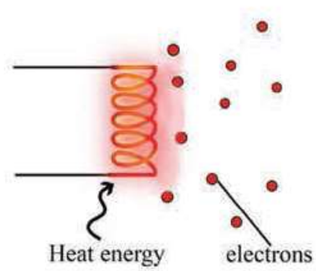


Figure 11.1 Thermionic emission

Vacuum Diode

Vacuum diode is the simplest form of vacuum tube. It consists of two electrodes, a cathode and an anode (or) plate. The cathode emits the free electrons by thermionic emission. It is an electron emitter. The anode collects the electrons. A vacuum diode is used as an AC (alternative current) to DC (direct current) converter.

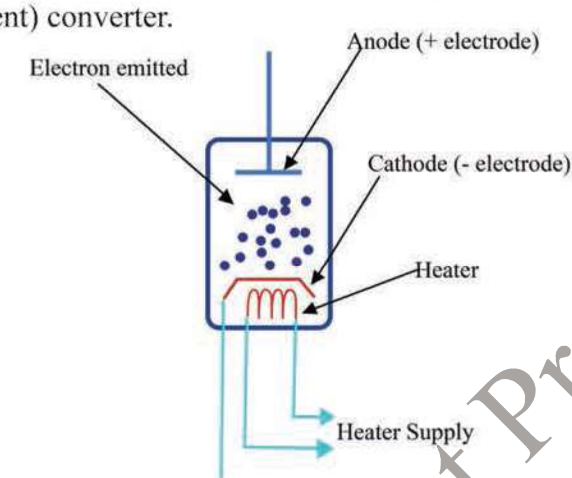


Figure 11.2 Vacuum diode

Some other vacuum tubes consisting of more than two electrodes are used as amplifiers. Nowadays, vacuum tubes are obsolete, having been replaced by transistors and semiconductor diodes.

Reviewed Exercise

1. Under what condition does the thermionic emission occur?
2. What is vacuum diode?

Key Words : thermionic emission, diode

11.2 BLACKBODY RADIATION AND THE CONCEPT OF PHOTON

At the end of 19^{th} century scientists felt that all the laws of physics (which were known at that time) are enough to explain all the events occur in nature. It was believed that there are only two kinds of physical entities in nature, particles and radiation. All particles obey Newton's laws of motion and radiation obeys Maxwell's equations of electromagnetism. These laws are nowadays known as the laws of classical physics. Fortunately, physicists had performed some experiments which led to the development of modern concept of physics. The results of these experiments (such as blackbody radiation, photoelectric effect and Compton effect) could not be explained by the laws of classical physics.

Blackbody Radiation

A blackbody is a perfect radiator of light that absorbs and emits all radiation incident on it. Its light output depends on its temperature. The sun and stars emit radiation like a blackbody. A blackbody is physically realized by a small hole in the wall of a cavity radiator as shown in Figure 11.3.

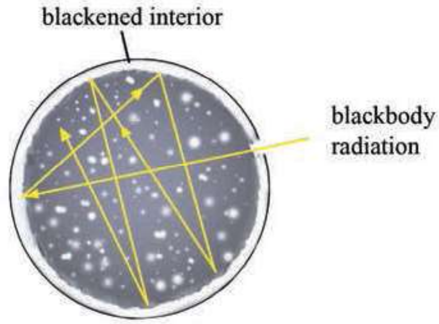


Figure 11.3 A blackbody represented by a small hole in the wall of a cavity

When a blackbody is heated, the radiation it emits is called blackbody radiation. Intensity of radiation is the energy emitted from unit area of the surface in one second. The graph drawn with the intensity of blackbody radiation against the wavelength at a given temperature is called blackbody spectrum as shown in Figure 11.4.

> The variation of intensity with the wavelength of this radiation at a given temperature gives a blackbody spectrum.

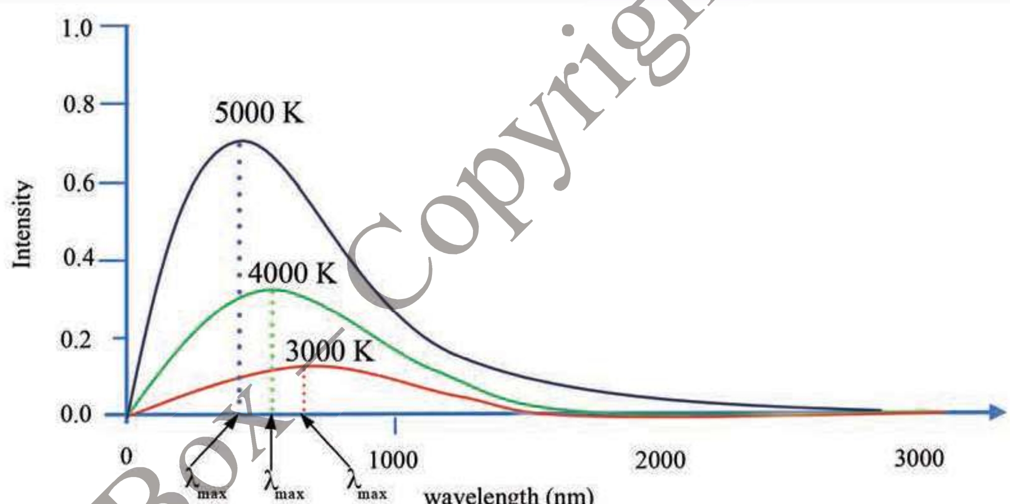


Figure 11.4 Intensity versus wavelength curve of the blackbody radiation at different temperatures

Two distinct features which can be observed from the blackbody spectrum are given as Wien's law and Stefan's law.

(i) Wien's Law

The wavelength at which maximum intensity occurs (λ_{max}) is inversely proportional to the absolute temperature of the blackbody. That is,

$$\lambda_{max} \propto \frac{1}{T}$$

It means that the higher the temperature, the shorter the wavelength λ_{max} .

(ii) Stefan Boltzmann's Law

The total emissive power of a blackbody (ε_0) is directly proportional to the fourth power of absolute temperature.

$$\varepsilon_0 = \sigma T^4, \ \sigma = \text{Stefan's constant}$$

It means that the higher the temperature, the higher the energy radiated.

These experimental observations of the blackbody spectrum could not be explained by classical physics.

Max Planck's Explanation of the Blackbody Radiation and the Concept of Photon

Detailed explanation of the blackbody radiation is given by Max Planck in 1900. Planck proposed that the radiation resulted from a large number of identical oscillators. Radiation is emitted (or absorbed) when an oscillator changes energy level. The emitted radiation from the oscillator can be thought of as particles called photons which carry energy. Although they are named particles they are chargeless and massless and travel with the speed of light c.
Plank assumed that the energy of a photon was proportional to its frequency, that is,

$$E \propto f \quad \text{(or)} \quad E = hf = h\frac{c}{\lambda}$$

where the constant h is the Planck constant and λ is the wavelength of the emitted radiation (photon).The numerical value of the Planck constant is $h = 6.626 \times 10^{-34}$ Js.

We see that photons with a long wavelength have *low* energy and photons with short wavelength have *high* energy. Suppose a certain amount of energy of a photon is given by hf and the number of photons is n, then the total energy is nhf. Since the number of photons must always be expressed as an integer, one can say that, for different values of n, the energy must have come in discrete amounts. That is, the simple quantum concept for energy of photons. A quantum of energy is the energy difference between the two allowed discrete values without ever reaching intermediate values. Quantized energies are discrete but not continuous.

Planck introduced the quantum concept as a modification of classical ideas that brought his theory into agreement with experimental observations.

Example (1) The energy of a single light photon is $E = hf$, the Planck's constant $h = 6.626 \times 10^{-34}$ Js, visible light wavelength is $\lambda = 0.5$ μm. Find the energy of the visible light. (1 eV = 1.6×10^{-19} J)

$h = 6.626 \times 10^{-34}$ Js , $\lambda = 0.5$ μm , $c = 3 \times 10^8$ m s^{-1}

Since $c = f\lambda$,

$$E = hf = \frac{hc}{\lambda} = \frac{6.626\times10^{-34}\times3\times10^8}{0.5\times10^{-6}}$$

$$= 4 \times 10^{-19} \text{ J}$$

$$= \frac{4\times10^{-19}}{1.6\times10^{-19}} = 2.5 \text{ eV}$$

Example (2) The energy of a certain incident ray is 4.14 eV. What is the frequency of this incident ray?

$E = 4.14 \text{ eV} = 4.14 \times 1.6 \times 10^{-19}$ J

From $E = hf$, one has

$$f = \frac{E}{h} = \frac{4.14 \times 1.6 \times 10^{-19}}{6.626 \times 10^{-34}} \text{ (or) } \frac{4.14}{4.14 \times 10^{-15}}$$

$= 10^{15}$ Hz

Reviewed Exercise

- Express the numerical value of the Plank constant h in terms of eVs.

Key Words : blackbody, spectrum, photon, quantized energy

11.3 MODELS OF ATOM

Thomson's Model

The discovery of the electron in 1897 prompted JJ. Thomson (1856 -1940) to suggest a model of the atom. He suggested that an atom might be a spherical volume of positive charge with electrons embedded inside it like currant in a bun (or) plums in a pudding. For this reason, Thomson's model is called the plum pudding model of the atom.

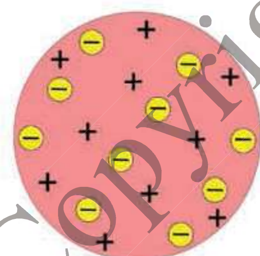


Figure 11.5 Thomson's plum pudding model of the atom
[https://www.electrical 4u.com/thomson-plum-pudding-model]

Rutherford's Model

Under the supervision of Ernest Rutherford (1871-1937), Hans Geiger and Ernest Marsden performed an important experiment in 1911. It produced results which could not be explained by Thomson's model.

In this experiment, a thin metal foil was bombarded with a beam of positively charged alpha particles. Most of the alpha particles passed straight through the foil, but a few were deflected from their original direction through very large angles. Some particles were even deflected backward as shown in Figure 11.6. The whole experiment setup is kept in the vacuum.

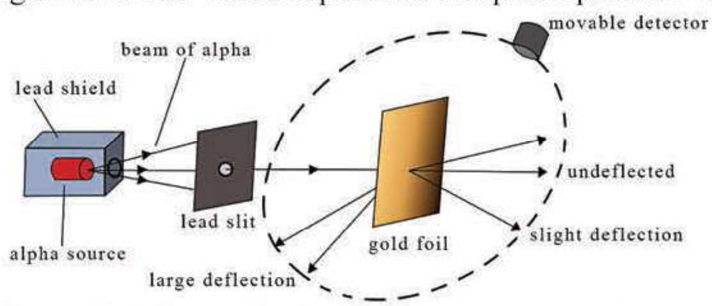


Figure 11.6 Rutherford's alpha scattering experiment

Such large deflections were completely unexpected on the basis of Thomson's model, in which positive charges are evenly distributed throughout the atom. Hence the positively charged alpha particles would never experience large enough repulsive force to cause large-angle deflections.

On the basis of his observation, Rutherford concluded that the atom must be largely empty space with all of its positive charges and most of its mass concentrated in a small region. This concentrated volume at the centre of the atom is called the nucleus. Negatively charged electrons are moving around the tiny nucleus as shown in Figure 11.7.

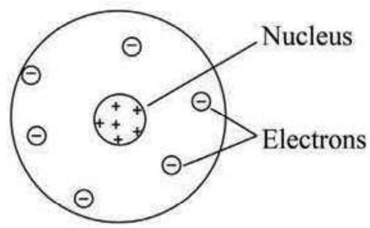


Figure 11.7 Rutherford's model of the atom

Bohr's Model

In 1913, Niels Bohr (1885 - 1962), a Danish Physicist, proposed a new model of the atom by applying the quantum theory. In Bohr's model, the electrons move in circular orbits around the nucleus. The electric force between the positively charged proton inside the nucleus and the negatively charged electron holds the electron in orbit. However, only certain orbits are allowed in this model. The electron is never found between the allowed orbits. However it can jump from one orbit to another. Bohr assumed that the atom does not emit energy in the form of radiation when the electron is in an allowed orbit. Hence the total energy of the atom remains constant and it resolved the instability of the atom which is a difficulty of the Rutherford model.

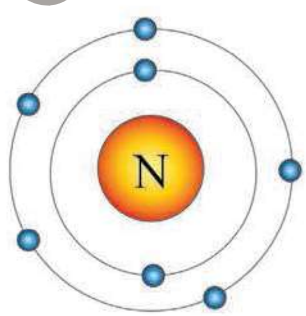


Figure 11.8 Bohr's model of the atom

Reviewed Exercise

- Discuss the essential differences among Thomson's model, Rutherford's model and Bohr's model of an atom.

Key Words : alpha particle, nucleus, electron, proton

11.4 ATOMIC STRUCTURE

All matter is made of atoms. Atoms are too tiny to be seen with any ordinary microscope. Atoms are composed of smaller particles called electrons, protons and neutrons. There is a central nucleus made up of protons and neutrons. Around this, electrons orbit at high speed in allowed orbits. A simple model of the atom is illustrated in Figure 11.9.

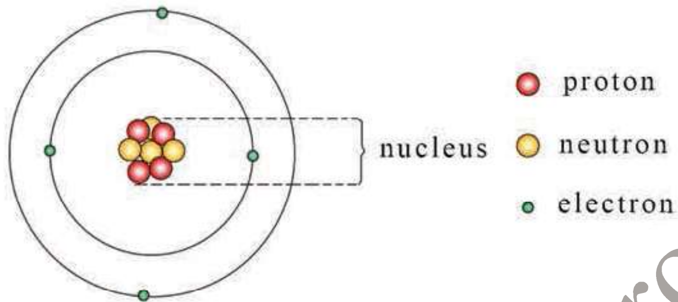


Figure 11.9 An illustration of an atom

Protons have a positive charge and electrons have an equal negative charge, while the neutrons are neutral. An atom has the same number of electrons as protons, so its total charge is zero. Thus, atom as a whole is neutral. Together, protons and neutrons are known as nucleons. Protons and neutrons have similar masses and electrons are the lightest. Protons and neutrons are about 1800 times more massive than an electron, so all of an atom's mass is concentrated in its nucleus. Electrons are held in orbit by the Coulomb attractive force of the nucleus. Protons and neutrons are bound tightly together in the nucleus by the strong nuclear force. The properties of these particles are summarized in Table 11.1.

Table 11.1 Comparison of proton, neutron and electron of an atom in terms of charge and mass

Particle	Position	Charge (C)	Mass (kg)
Proton	in the nucleus	$+1.6 \times 10^{-19}$	1.67×10^{-27}
Neutron	in the nucleus	0	1.67×10^{-27}
Electron	orbiting nucleus	-1.6×10^{-19}	9.11×10^{-31}

Atomic Number

All materials are made from about 100 basic substances called elements. An atom is the smallest piece of an element. The atomic number of an element tells us how many protons (or) electrons are in an atom of that element. It is written as symbol Z. Each element has its own unique atomic number. The atomic number is sometimes called the proton number. The chemical properties of an element is determined by the number of electrons in the atom, that is atomic number.

Mass Number

The total number of protons and neutrons in the nucleus of an atom is called the mass number (or) the nucleon number. The mass number of an element is given the symbol A.

Symbol of Atom

An atom of an element with atomic number Z and the mass number A is represented by its chemical symbol X as ${}_{Z}^{A}X$.

Mass number = Number of neutrons + Number of protons = Number of nucleons

Number of neutrons = Mass number – Number of Proton

= Mass number – Atomic Number

Number of neutrons = $A - Z$

Elements and isotopes

Although atomic number of an element does not change, atoms of the same element can have different mass numbers. This is because the number of neutrons in a particular element can vary.

Atoms that have the same atomic number but different neutron numbers (and thus different mass numbers) are called isotopes. They have identical chemical properties, although their atoms have different masses. Most elements are a mixture of two (or) more isotopes.

Hydrogen has three isotopes protium or hydrogen (${}_{1}^{1}H$), deuterium (${}_{1}^{2}H$) and tritium (${}_{1}^{3}H$).

Figure 11.10 Three isotopes of hydrogen

Reviewed Exercise

1. Is it possible for the atom of an element to have one electron, one proton and no neutron? If so, name the element.
2. Which force holds the electrons and nucleus of an atom to form an atom?

Key Words : atomic number, mass number, isotope

11.5 THE STRUCTURE AND EVOLUTION OF THE VISIBLE UNIVERSE

The part of the universe which we can see is termed the visible universe. The actual universe might be bigger than the visible universe. The part we can see is determined by the age of the universe. For example, suppose that the universe is 1.38×10^{10} years old, as indicated by currently available astrophysical measurements. That means the farthest away from the earth that we can see, in any direction, is 4.65×10^{10} light year, i.e. the distance light can travel in the time since the universe was formed.

To learn the fundamentals of the universe one needs to study astronomy, astrophysics and cosmology which are three closely related subjects. Differences come from the domains and goals of the study of the three fields.

Astronomy is a natural science that deals with the study of celestial objects, which are any natural bodies outside of the earth's atmosphere. Examples are the Moon, the Sun, planets, stars, comets, nebulae, star clusters and galaxies, etc.

Astrophysics is the branch of astronomy that deals with the physics of the universe, including the physical properties of celestial objects, as well as their interactions and behavior. Among the objects studied are galaxies, stars, planets, exoplanets, the interstellar medium and the cosmic microwave background.

Cosmology studies the universe as a whole and its phenomena at largest scales. The difference between Astrophysics and Cosmology is the domain and scale of the study.

A Brief Outline of the Universe

The Earth, our planet is part of the solar system that contains eight planets and the Sun. The Sun is a star and there are many others like it in the universe. The closest star to our own is called Proxima Centauri, together with approximately 10^{11} other stars they make up the Milky Way.

The Milky Way is one of about 10^{11} galaxies in the visible universe. Therefore, the visible universe consists of roughly 10^{22} stars. Galaxies cluster into groups; our group is labeled the Local Group and contains about 30 galaxies. The main force holding all of these systems together is gravity.

Units in Measuring Astronomical Distances

Astronomers have created units of measurement for astronomical distances. One of these units is called an Astronomical Unit (AU), the mean distance between the Earth and the Sun, that is, 1.496×10^8 km. The light year is an another astronomical unit for measuring large distances. The light year (*l*y) is the distance travelled by light in a vacuum in one year. One simply has,

$$1\ ly = 60\times60\times24\times365\times3\times10^{8} = 9.46\times10^{15}\ \text{m} = 9.46\times10^{12}\ \text{km}$$

One parsec (pc) is the distance to a star that subtends an angle of 1 arc sec (arc second) at an arc length of 1 AU.

Through trigonometry, the distance SD (Figure 11.11) is calculated as follows.

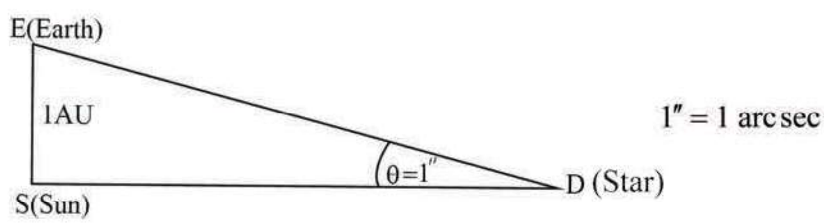


Figure 11.11 An Astronomical triangle

From the above figure , one gets

$SD = \dfrac{ES}{\tan\theta}$ since the tangent θ is very small, one has tangent θ , and $\theta = 1''$.

It has been known that 1 degree = $\dfrac{\pi}{180}$ = 60 × 60 = 3600 arc sec

1 arc sec = $\dfrac{\pi}{60 \times 60 \times 180}$

then SD can be written as

$$SD \approx \frac{ES}{1''} = \frac{1\ AU}{\frac{1}{60\times 60} \times \frac{\pi}{180}} = \frac{648\ 000}{\pi} AU \approx\ 206\ 264.81\ AU.$$

$$SD = 1pc = 206\ 264.81 \times 1.496 \times 10^8$$

$$= 3.08 \times 10^{13}\ km$$

Table 11.2 Comparison of measuring units for astronomical distances

Astronomical Unit	AU	1 AU = 1.496×10^8 km
light year	*ly*	1 *ly* = 9.46×10^{12} km
parsec	pc	1 pc = 3.08×10^{13} km
		1 pc = 3.26 *ly* 1 pc = 206 265 AU

Evolution of the Universe

Astrophysicists and astronomers have theorized that the universe must have originated at a single point of infinite density and finite time then began to expand. This is known as the Big Bang theory. After the initial expansion, the theory maintains that the universe cooled sufficiently to allow the formation of subatomic particles, and later simple atoms. Giant clouds of these primordial elements later coalesced through gravity to form stars and galaxies. This all began roughly 13.8 billion years ago, and is thus considered to be the age of the universe. Scientists have constructed through the testing of theoretical principles and extensive experiments a timeline of events that began with the Big Bang up to the current state of cosmic evolution. These experiments involve astronomical studies that have observed the deep universe.

Table 11.3 Physical Data of the Visible Universe

Diameter	8.8×10^{26} m (28.5 Gpc or 93 G*ly*)
Volume	4×10^{80} m^3
Mass (ordinary matter)	4.5×10^{51} kg
Density (of total energy)	9.9×10^{-27} kg m^{-3} (equivalent to 6 protons per cubic meter of space)
Age	1.38×10^{10} years (or) 13.799 billion years
Average temperature	2.725 48 K
Contents	• Ordinary matter (4.9%) • Dark matter (23%) • Dark energy (72%)

Reviewed Exercise

- What is the light year?

Key Words : astronomy, astrophysics, cosmology

SUMMARY

Blackbody Radiation

A blackbody is a perfect radiator of light that absorbs and re-emits all radiation incident on it. Its light output depends on its temperature. The sun and stars emit radiation like a blackbody.

Wien's Law is the wavelength at which maximum intensity occurs (λ_{max}) is inversely proportional to the absolute temperature of the blackbody.

Stefan's Law is the total amount of energy emitted by a blackbody is proportional to the fourth power of absolute temperature.

Astronomy is a natural science that deals with the study of celestial objects, which are any natural bodies outside of the earth's atmosphere. Examples are the Moon, the Sun, planets, stars, comets, nebulae, star clusters and galaxies.

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Cosmology studies the universe as a whole and its phenomena at largest scales. The difference between Astrophysics and Cosmology is the domain and scale of the study.

The Visible Universe

The part of the universe which we can see is termed the visible universe. The actual universe might be bigger than the visible universe.

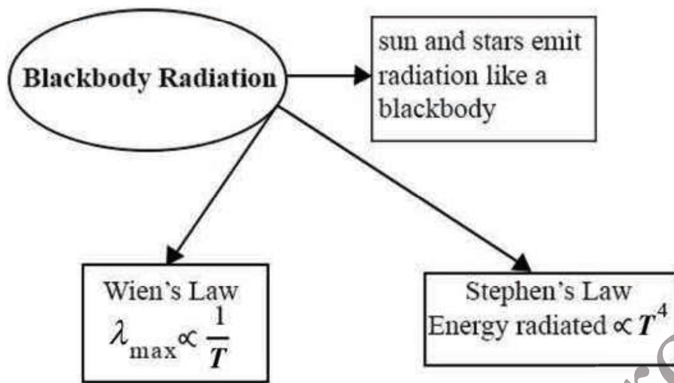
EXERCISES

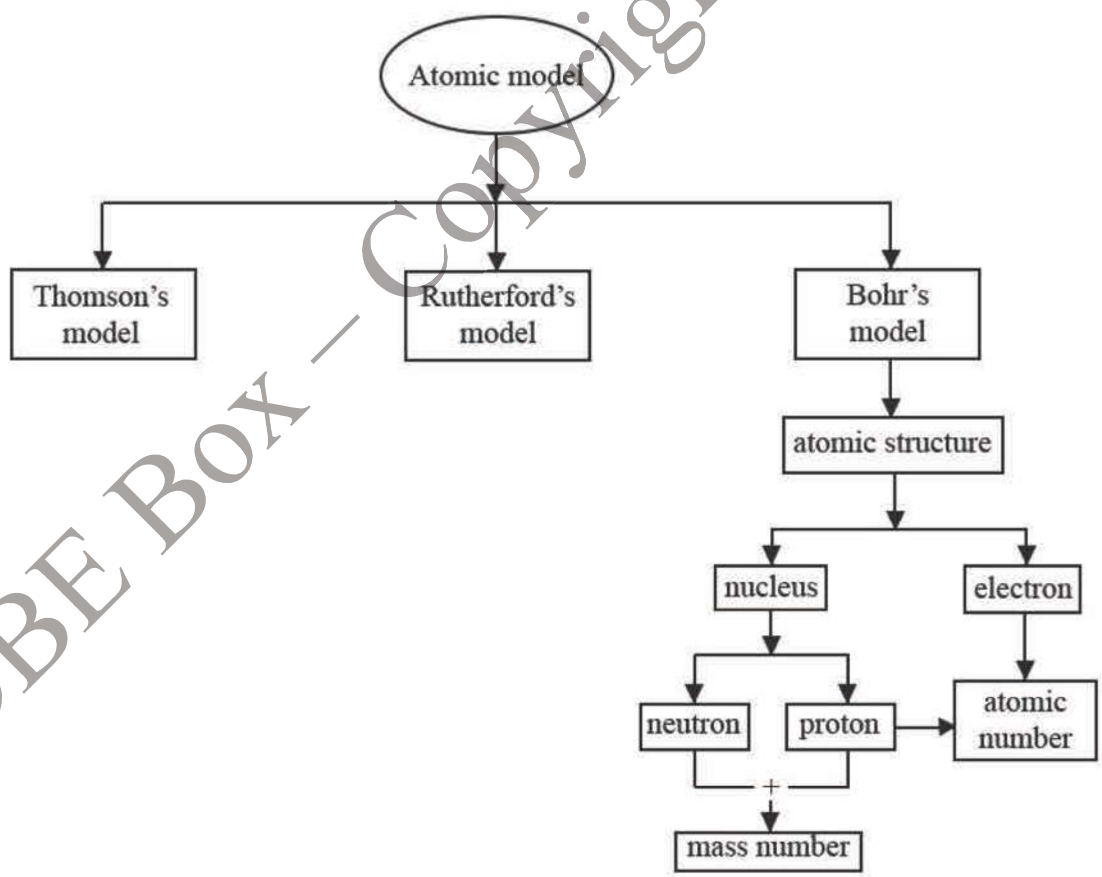
Choose the correct answer for the following.

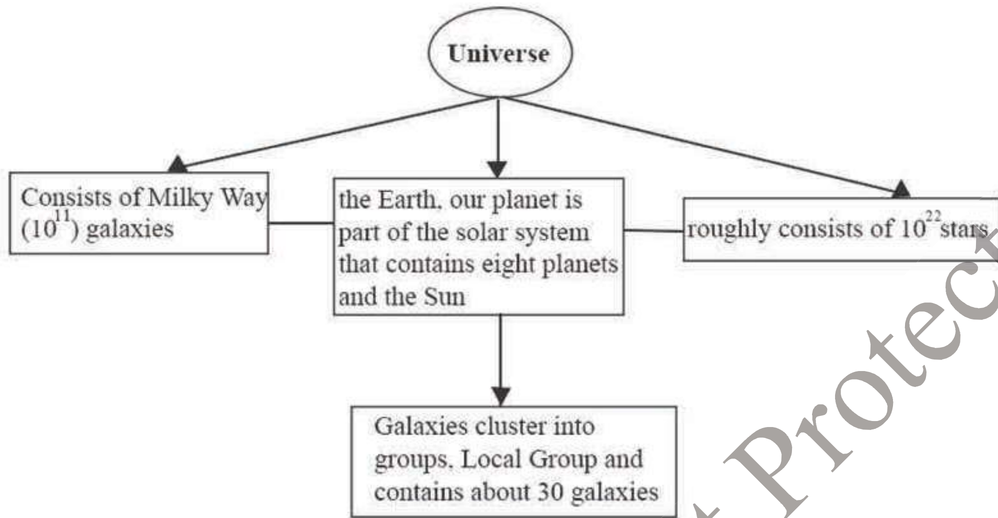
1. The main force responsible for the formation of the universe is:
   A. gravity C. magnetic force
   B. frictional force D. electrical force
2. The approximate age of the universe is:
   A. 1 billion years old and 14 days C. 140 billion years old
   B. 14 billion years old D. 13.7 billion years old
3. The first objects to form in the solar system were
   A. atoms C. comets
   B. stars D. planets

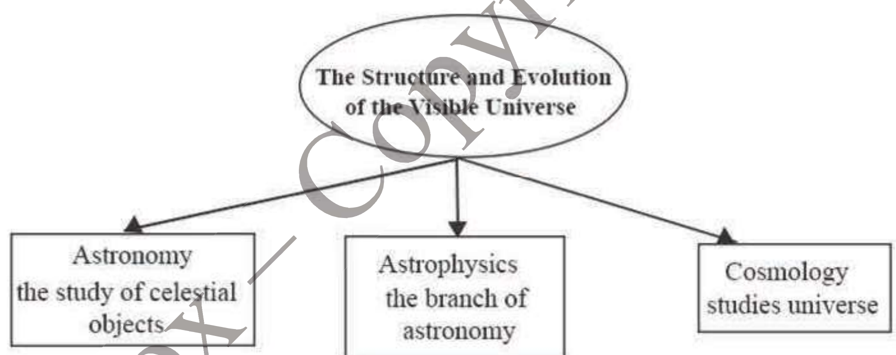
4. Which of the following correctly lists the structures in space from smallest to largest?
   A. Stars, Galaxy, Universe, solar system
   B. Stars, solar system, Galaxy, Universe
   C. Stars, solar system, Universe, Galaxy
   D. Stars, Universe, Solar system, Galaxy
5. Our galaxy, the Milky Way, has a pinwheel shape, what type of galaxy is it?
   A. elliptical
   B. fun
   C. irregular
   D. spiral
6. Which of the following is the best estimate of the number of stars in a typical galaxy?
   A. hundreds
   B. thousands
   C. millions
   D. billions
7. Which of the following is the best estimate of the number of galaxies in the universe?
   A. hundreds
   B. thousands
   C. millions
   D. billions
8. A light year measures
   A. the distance it takes light to travel in 1 year
   B. the distance between stars
   C. the speed of light
   D. the wavelength of visible light
9. Which of the following is the smallest?
   A. the earth
   B. the universe
   C. a galaxy
   D. the sun
10. Which of the following is the largest?
    A. the earth
    B. the universe
    C. a galaxy
    D. the sun
11. What is the frequency of a photon whose energy is 66.3 eV? $\left(1\text{eV} = 1.6\times10^{-19}\text{J},\ h = 6.625\times10^{-34}\text{Js}\right)$
12. Which subatomic particle has a negative charge?
13. Which subatomic particle has a positive charge?
14. Which subatomic particle is a neutral?
15. What is thermal radiation? How does it differ from other form of electromagnetic radiation?
16. An atom contains electrons, protons, and neutrons. Which of these particles (a) are outside the nucleus (b) are uncharged (c) have a negative charge (d) are nucleons (e) are much lighter than the others?
17. An aluminium atom has an atomic number of 13 and a mass number of 27. How many (a) protons (b) electrons (c) neutrons does it have?
18. Chlorine is a mixture of two isotopes, with mass numbers 35 and 37. What is the difference between the two types of atom?

CONCEPT MAP


Blackbody Radiation
sun and stars emit radiation like a blackbody
Wien's Law
$\lambda_{max} \propto \frac{1}{T}$
Stephen's Law
Energy radiated $\propto T^4$


Atomic model
Thomson's model
Rutherford's model
Bohr's model
atomic structure
nucleus
electron
neutron
proton
atomic number
+
mass number


Universe
Consists of Milky Way (10^{11}) galaxies
the Earth, our planet is part of the solar system that contains eight planets and the Sun
roughly consists of 10^{22} stars
Galaxies cluster into groups, Local Group and contains about 30 galaxies


The Structure and Evolution of the Visible Universe
Astronomy
the study of celestial objects
Astrophysics
the branch of astronomy
Cosmology
studies universe

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APPENDIX

CONVERSION FACTORS

Length

1 metre (m)	= 100 cm = 1 000 mm	1 foot (ft)	= 30.48 cm = 0.304 8 m
	= 39.4 in		
	= 3.28 ft	1 inch (in)	= 0.083 3 ft
1 centimetre (cm)	= 0.394 in		= 2.54 cm
1 kilometre (km)	= 1 000 m	1 mile (mi)	= 1.61 km
	= 0.621 4 mi		= 5 280 ft

Area

1 m^2	= 10^4 cm^2	1 ft^2	= 0.092 9 m^2
	= 1.55×10^3 in^2		= 929 cm^2
	= 10.76 ft^2		= 144 in^2
1 cm^2	= 10^{-4} m^2	1 in^2	= 6.452 cm^2
	= 0.155 in^2		

Volume

1 m^3	= 10^6 cm^3	1 ft^3	= 0.028 3 m^3
	= 35.3 ft^3		= 28.3 litres
	= 6.10×10^4 in^3		= 7.48 gal
1 in^3	= 16.39 cm^3	1 liter	= 1 000 cm^3 = 10^{-3} m^3
			= 0.035 1 ft^3
			= 61 in^3

Mass

1 kilogram (kg)	= 0.068 5 slug (sl)	1 sl	= 14.57 kg
	= 1 000 g	1 lb	= 454 g
			= 0.454 kg

Time

1 day	= 1.44×10^3 min	= 8.64×10^4 s	
1 year	= 8.76×10^3 h	= 5.26×10^6 min	= 3.15×10^7 s

Angle

1 radian (rad)	= 57°18′ =57.30°	1°	= 0.01745 rad

Greek Alphabet

Α	α	Alpha	Ν	ν	Nu
Β	β	Beta	Ξ	ξ	Xi
Γ	γ	Gamma	Ο	ο	Omicron
Δ	δ	Delta	Π	π	Pi
Ε	ε	Epsilon	Ρ	ρ	Rho
Ζ	ζ	Zeta	Σ	σ	Sigma
Η	η	Eta	Τ	τ	Tau
Θ	θ	Theta	Υ	υ	Upsilon
Ι	ι	Iota	Φ	ϕ	Phi
Κ	κ	Kappa	Χ	χ	Chi
Λ	λ	Lambda	Ψ	ψ	Psi
Μ	μ	Mu	Ω	ω	Omega